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HOOVER STEEL BALL CO.

ANN ARBOR, MICHIGAN

MANUFACTURERS OF

B-A-L-L-S

STEEL, BRONZE, BRASS
COPPER, ALUMINUM
AND OTHER MATERIALS IN BOTH
HIGH AND COMMERCIAL GRADES



"MADE IN AMERICA"

TO THOSE WHO ARE INTERESTED IN OUR PRODUCT WE WILL,
UPON APPLICATION, GLADLY FORWARD OUR REGULAR CATALOG
AND PRICE LIST, GIVING THE TRADE NAME OF OUR DIFFERENT
GRADES OF BALLS, GUARANTEED ACCURACY AND QUALITY,
PRICES AND TERMS



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F O R E W O R D

WE TAKE PLEASURE IN PRESENTING THIS TREATISE ON THE MANUFACTURE OF STEEL BALLS AND WISH TO THANK THOSE WHO HAVE SUPPORTED US IN SUCCESSFULLY OVERCOMING THE PREJUDICE AT ONE TIME EXISTING AGAINST AMERICAN MADE BALLS.

THIS SUCCESS HAS BEEN DUE TO THE QUALITY OF OUR PRODUCT COMBINED WITH EXPERT KNOWLEDGE OF THE REQUIREMENTS OF OUR CUSTOMERS.

IN THE FOLLOWING PAGES WE HAVE ENDEAVORED TO SHOW STEP BY STEP THE VARIOUS STAGES THROUGH WHICH A BALL PASSES FROM THE ROUGH STEEL BLANK TO THE MIRROR-LIKE FINISHED SPHERE.

THE OBJECT OF THIS TREATISE IS TO LAY BARE FACTS WHICH HAVE HITHERTO BEEN GENERALLY UNKNOWN AND IF WE SUCCEED IN STIMULATING FURTHER INTEREST IN THE BALL INDUSTRY, THIS WORK WILL NOT HAVE BEEN IN VAIN.

HOOVER STEEL BALL CO.

ANN ARBOR, MICHIGAN



L. J. HOOVER
PRESIDENT AND GENERAL MANAGER



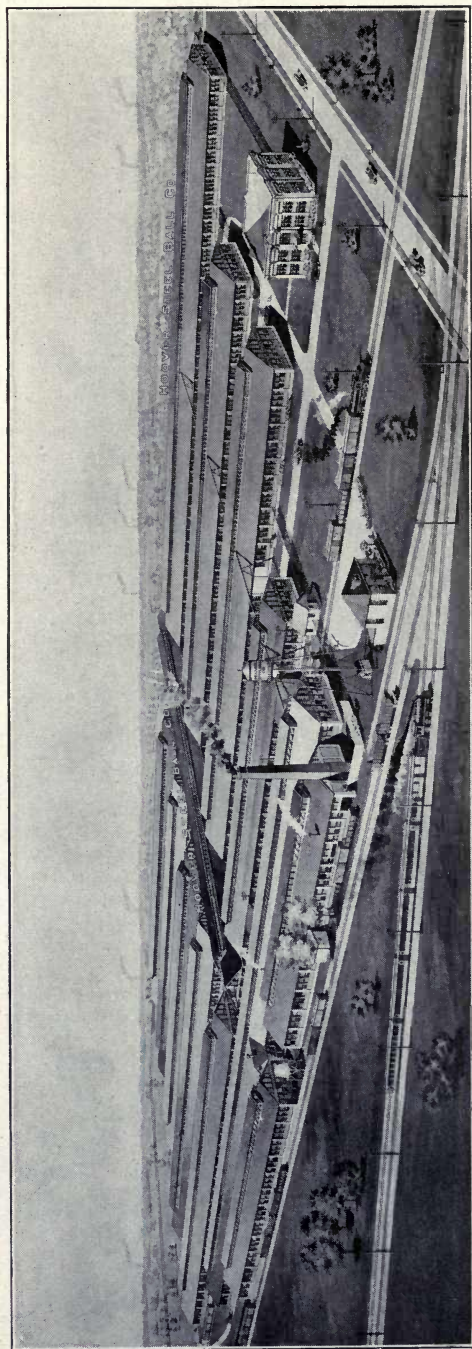
H.D. Runciman, Secy & Asst. Mgr.



W.H. Heselschwerdt, Purch. Agt.



R.J. Schenk, Head of Production Dpt.



HOME OF THE HOOVER STEEL BALL
PRESENT PLANT 1917

Manufacture of Steel Balls

DURING recent years the application of ball bearings in machine design has increased rapidly, and this type of bearing is now used in many machines where plain bearings were formerly considered good enough. Until German export facilities were shut off by the war, the majority of the steel balls used in these bearings were made by the Deutsche Waffen und Munitions Fabriken of Berlin, Germany, and the product of this firm has become so celebrated that many persons think the steel ball industry was developed by the Germans. As a matter of fact, the art of ball making goes back to a very early date, and the development of original methods for doing this work is attributed to the Chinese. To those who have credited the Germans with the development of commercial methods of ball manufacture, it will doubtless be of interest to learn that the first commercial steel balls were made in this country under basic patents granted to Richardson of the Waltham Emery Wheel Co., Waltham, Mass., and that the original ball making machinery for the plant of the Deutsche Waffen und Munitions Fabriken was designed and built in the United States and shipped to Germany ready for use. This will be explained in detail in connection with the following historical outline of important epochs in the steel ball industry.

HOW THE STEEL BALL INDUSTRY CAME INTO EXISTENCE

IT HAS been stated that basic patents for dry grinders used in roughing out ball blanks to a spherical form were granted to Richardson of the Waltham Emery Wheel Co., in 1887. These patent rights were subsequently sold to the Cleveland Machine Screw Co., Cleveland, Ohio, which had control of patents on ball making machinery taken out by John J. Grant.

One of the first firms to manufacture steel balls on a commercial basis was the Simonds Rolling Machine Co., of Fitchburg, Mass., and the Fitchburg Steel Ball Co. was subsequently formed by employees who left the Simonds firm. After a brief career,

the latter firm was taken over by the Cleveland Machine Screw Co., and with facilities acquired through its own development work and purchase from other companies, it was in a position to manufacture the majority of balls used in the bicycle trade. In this connection it will be of interest to note that up to the year 1899 balls one-half inch in diameter were the largest size that were manufactured in quantities.

About 1890 the Cleveland Machine Screw Co. designed and built for the Deutsche Waffen und Munitions Fabriken, of Berlin, Germany, equipment used in its original steel ball plant and this marked a most important step in the trade, owing to the reputation for making high-grade balls that was later acquired by this firm. The machines built and shipped to Germany had no reference to American manufacturing rights, and the Cleveland Machine Screw Co. continued to operate its plant in the usual way.

In 1894 when a consolidation of bicycle manufacturers was effected, the Cleveland Machine Screw Co. was sold to the Pope Mfg. Co. of Hartford, Conn., which at that time started to manufacture its own balls for use in bicycle bearings. The requirements of balls for the bicycle trade were not nearly as severe as the standards which must be met by balls used in high-grade annular bearings at the present time. This was largely due to the fact that the cup and cone form of races was employed, allowing compensation to be made, and while this form of race did not enable ball bearings to be operated under the most efficient conditions, it was the means of overcoming discrepancies due to inaccuracies in the size of the balls. Up to this time there had been six or seven firms engaged in the manufacture of steel balls, but with the decline of the bicycle industry a number failed.

In 1901 the Standard Roller Bearing Co., Philadelphia, Pa., acquired all obsolete and existing plants engaged in the manufacture of steel balls. L. J. Hoover, who was formerly in the employ of the Standard Roller Bearing Co., left that firm in 1906 and formed the Grant & Hoover Co. at Merchantville, N. J. The name of this firm was later changed to Atlas Ball Co., and the plant transferred to Philadelphia, Pa., where it is still in operation. On March 1, 1913, the Hoover Steel Ball Co. of Ann Arbor, Mich., was organized by Mr. Hoover for the

purpose of engaging in the manufacture of high-grade steel balls to take the place of those imported from Germany. When the European war started in 1914, the blockade of German ports by the British Navy shut off the supply of steel balls formerly exported by that country to the United States, and the insistent demand of consumers for balls made in this country imposed a heavy strain upon the facilities of domestic producers. Somewhat similar conditions existed in all branches of the machinery trade, making it difficult for the ball manufacturers to increase the capacity of their plants; but the management of the Hoover Steel Ball Co. showed commendable initiative by contracting for the entire output of machine building firms with which orders were placed for special machinery required in ball manufacture; and these firms were given financial assistance to enable them to handle work with the greatest possible rapidity. As a result, the Hoover Steel Ball Co. has greatly increased its capacity, the growth being well illustrated by Fig. 1 and the illustration in the center of the book, that show, respectively, the original factory in which the firm started manufacturing in March, 1913, and the plant as it appears at present. An idea of the magnitude of the business will be gathered from the fact that the consumption of steel runs in excess of 500 tons a month, and calculated on the basis of $\frac{1}{4}$ -inch balls, the daily production is between 25,000,000 and 30,000,000 balls per day.

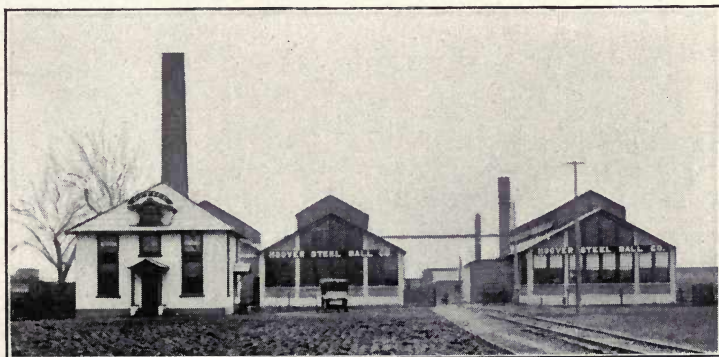


Fig. 1. Original Plant in which Hoover Steel Ball Co. started Manufacturing Operation in March, 1913.

RAW MATERIAL OF THE STEEL BALL INDUSTRY

THE steel from which balls are made comes to the factory in coils or straight rods, according to its size. Stock less than 11/16 inch in diameter comes in coils and is known as "wire," while all stock exceeding 5/8-inch in diameter comes in straight bars. The size of the stock is referred to in thousandths, *i. e.*, stock 3/8-inch in diameter is known as 0.375-inch stock. The following is a specification of steel wire used for making balls: carbon, 0.95 to 1.05 per cent; silicon, 0.20 to 0.35 per cent; manganese, 0.30 to 0.45 per cent; chromium, 0.35 to 0.45 per cent; sulphur and phosphorus, not to exceed 0.025 per cent. The following analysis is typical for the larger sizes of stock which comes in straight bars: carbon, 1.02 per cent; manganese, 0.40; silicon, 0.21; chromium, 0.65; sulphur, 0.026; and phosphorus, 0.014 per cent. A well equipped laboratory is maintained in which chemical and physical tests are conducted on each shipment of steel to determine its suitability for manufacture into balls, and an unloading ticket must be signed by the head of the laboratory before the steel is taken from the cars into the plant. Some very interesting conditions have been brought to light by the laboratory work, and a later section of this article will be devoted to a discussion of tests conducted on the raw material and product, data obtained from these tests, and a description of methods and apparatus used in the laboratory.

PRODUCTION OF BALL BLANKS BY COLD-HEADING

BALL blanks made from stock ranging from 1/16 up to and including 5/8-inch in diameter are formed on special cold-headers designed for the production of ball blanks by the E. J. Manville Machine Co., Waterbury, Conn. A battery of these machines is shown in operation in Fig. 2, and in this connection it may be mentioned that the Hoover Steel Ball Co. is equipped with machines of the following sizes: 00, 0, 1, 2, 3, and 5. Production of ball blanks by the cold-heading process has several advantages in its favor. In the first place, there is practically no waste, with the exception of about 0.040

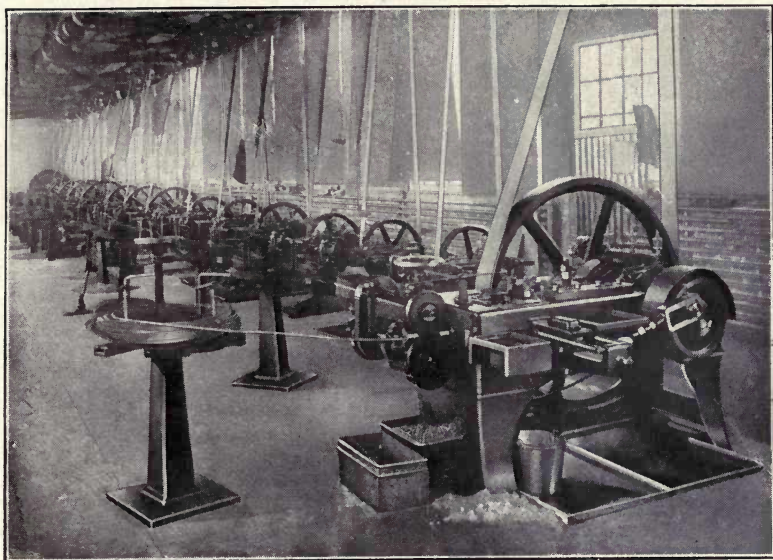


Fig. 2. General View in Cold-header Department; Blanks for All Sizes of Balls up to $\frac{3}{8}$ -inch Diameter are made on Cold-Heading Machines.

inch of metal left on the blank to provide for finishing. Blanks can be held to this close limit because the steel is worked cold and there is no tendency for it to become decarbonized. One man can look after three or four machines, so that the cost of labor is almost negligible. Cold-headers used in the production of ball blanks are of the type commonly known as single-blow solid-die machines, and the way in which they operate can best be explained in connection with Fig. 3. These machines consist of a heavy frame *A* which completely surrounds the working parts of the machine, thus insuring a high degree of rigidity. At one end of the machine there is a driving shaft *B*; and at the opposite end of the frame is die-block *C*. Between the sides of the frame is a movable ram *D* that actuates the heading punch *E*. Wire *F* to be made into ball blanks enters the machine through feed rolls *G* and then passes through cut-off quill *H*. At the side of the machine is supported a bracket *I* in which slide *J* may be reciprocated by a crank motion from the main driving shaft. Slide *J* has a cam groove cut in it in which roll *K* is fitted; this roll is mounted on cross-slide *L*, so that a lateral

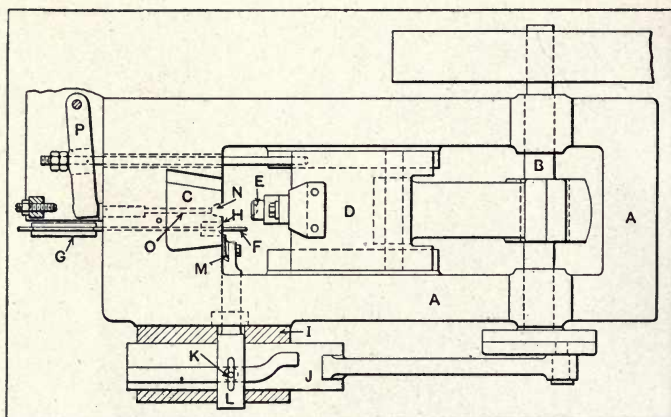


Fig 3. Plan View of Cold-header Mechanism Illustrating Method of Operation.

motion is imparted to cut-off knife *M* located on the end of cutter-bar *L*.

A ratchet feed advances the wire through the cut-off quill until it comes into contact with a stop, which is not shown in the illustration. This stop checks forward motion of the stock when a sufficient length has passed the cut-off knife to produce a ball blank of the proper size. Cut-off knife *M* is advanced in the manner just described, severing the wire, but retaining it on the cut-off blade by means of a spring finger. Advance of the cut-off knife and wire slug is continued until the slug reaches a position directly in front of the opening in die *N*. Here it is held stationary long enough for punch *E* to begin to push the slug of metal into the die, at which time cut-off knife *M* retreats

Table I. Capacities of Cold-headers in Ball Blanks per Hour

Size of Cold-header	Capacity for Ball Blanks Diameter in Inches. Max. Size.	Production of Blanks per Hour	Size of Cold-header	Capacity for Ball Blanks Diameter in Inches. Max. Size.	Production of Blanks per Hour
00	3/16	7800	2	7/16	6300
0	9/32	7200	3	1/2	6000
1	3/8	6900	5	9/16	4800

Note—Due to time loss in setting up, trouble with stock and breakdowns, the actual average rate of production is from 80% to 90% of above values.

Table II. Size of Stock Used for Making Balls on Cold-headers

Diameter of Ball—Inches	Diameter of Stock—Inches	Diameter of Ball—Inches	Diameter of Stock—Inches
1/8	.100	5/16	.235
5/32	.120	3/8	.275
3/16	.145	7/16	.320
7/32	.170	1/2	.365
1/4	.190	9/16	.395
9/32	.220	5/8	.440

and allows punch *E* to continue its work by pushing the blank to the bottom of the die cavity. After the slug *F* has been headed it is ejected by the knock-out pin *O*, which is advanced by the mechanism operated by lever *P*, which also receives its motion from a crank at the side of the machine connected to the main driving shaft. In this way the ball blank is knocked out of the die and dropped through an opening into a receptacle placed to receive it, this being clearly shown in Fig. 2. Table II gives the diameter of stock used in making blanks for several different sizes of balls, and is presented to show the enlargement that takes place during the heading operation. Various grades of steel have been used for making dies employed on the cold-headers, but the most satisfactory results have been obtained with the following grades: "Sanderson" or "Viking Special" made by the Crucible Steel Co. of America; "Intra" made by the Hermann Boker Co.; "Gyro" made by Braeburn Steel Co.; and tool steel made by William Jessop & Sons.

HOT-FORGING BALL BLANKS

IT HAS previously been stated that blanks for balls exceeding $\frac{5}{8}$ -inch in diameter are hot-forged from straight bars, and in handling this work multiple dies are employed which produce strings of balls containing up to ten balls, according to the size. The stock is heated in "Frankfort" furnaces made by the Strong, Carlisle & Hammond Co. of Cleveland, Ohio;

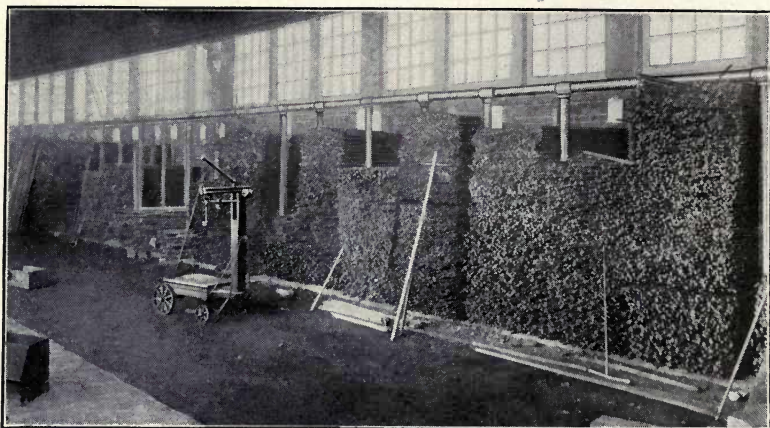


Fig. 4. View of Stock Racks in Hot-forging Department where Ball Blanks exceeding $\frac{3}{8}$ -inch diameter are made.

these are oil furnaces which are operated with oil at a pressure of 8 pounds per square inch, and air at a pressure of 2 pounds per square inch. Twelve bars are arranged in the furnace as shown in Fig. 5. The hammer-man takes out the bar at the left-hand side of the furnace, and after forging a string of balls at the end of this bar and cutting it up into individual ball blanks, returns the bar to the furnace at a point at the extreme right. In this way, the bars are used in rotation, which prevents any bar from becoming overheated. This is a matter of considerable importance, because the furnaces are maintained at a temperature somewhat in excess of 1800 degrees F. in order to provide for heating the stock as rapidly as may be necessary; but should it happen that steel was left in the furnace for an undue length of time, there would be danger of burning the steel.

The multiple forging dies are shown in detail in Fig. 6, in which it will be seen that each die opening is elliptical; the purpose of this is to provide a clearance space at each side into which excess metal will flow. It must be borne in mind however, that while this illustration only shows four die openings, the number of openings runs up to ten, according to the size of ball blanks that are being forged. In the cross-sectional views, the dimensions of the die are indicated by letters, and in Table III are given diameter *A* of cherrying cutter, distance *B* between

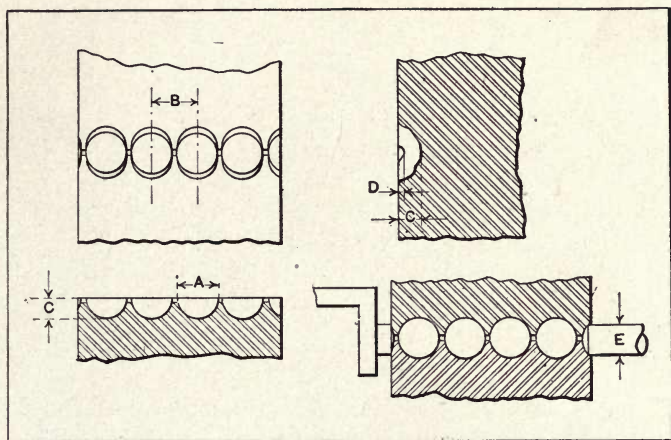


Fig. 6. Type of Die used for Hot-forging Ball Blanks for Balls exceeding $\frac{5}{8}$ -inch Diameter.

Table III. Dimensions of Hot-forging Dies for Ball Blanks

Diameter of Ball, Inch	Diameter A of Die, Inch	Distance B between Centers, Inch	Depth C of Die, Inch	Depth D, of Bridge, Inch	Diameter E of Stock, Inch
$\frac{3}{4}$	0.775	0.910	0.387	0.065	0.625
$\frac{7}{8}$	0.905	1.060	0.452	0.065	0.729
1	1.035	1.210	0.517	0.075	0.823

centers, and depth *C* to which the cherrying cutter is sunk in making the dies for three sizes of balls, and these data are presented to indicate how dimensions of the dies vary for different sizes of balls. The depth *D* of the gate between adjacent dies is a matter of considerable importance, because, it determines the size of the neck between adjacent balls, which is depended upon to hold the string of balls together until they are sheared. Also this depth must be regulated so that there is no tendency to draw the stock adjacent to the neck and form a pipe in the ball blank, which would have a highly detrimental effect on its structure. A land of approximately one-third the diameter of the ball is provided for clearance at the bottom of the die and the upper die member. The dies are made from a special die steel made by the Ludlum Steel Co. of Watervliet, N. Y., or from

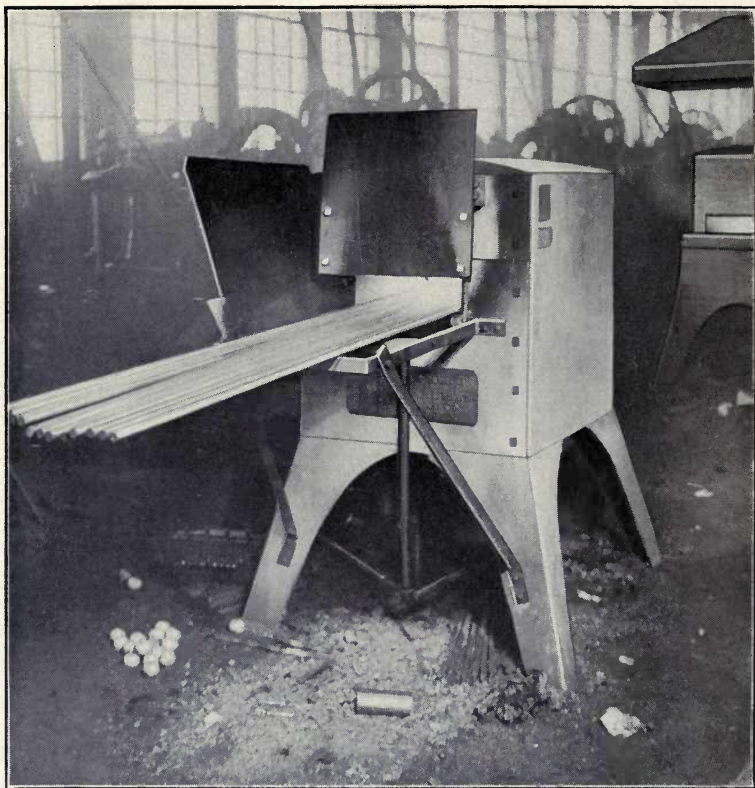


Fig. 5. "Frankfort" Oil-heated Furnaces made by Strong, Carlisle & Hammond Co., in which Bars are Heated for Hot-forging Operation.

"Firth-Sterling Special," made by the Firth-Sterling Steel Co., McKeesport, Pa. This is not an alloy steel, but a regular tool steel adapted for making hot-forging dies. In order to produce round balls in such dies, the bar is turned between each stroke of the hammer, which results in bringing the balls to a close approximation of the spherical form. Along one side of each die is a pipe with a number of holes drilled in it through which water flows onto the dies and work.

In purchasing stock for the production of ball blanks for the hot-forging method, it is matter of considerable importance to have all bars of the same length. This is due to the fact that when there is considerable variation in length, some bars will

be used up before others, with the result that it is necessary to finish up a number of short pieces in the furnace before putting in an entire new charge. At the end of each bar there is left what is known as a "short end," and experience has shown that these short ends cannot be forged into ball blanks of the regular size, as they fail to fill out the dies properly. On this account, short ends are collected and forged into ball blanks of the next smaller size. By ordering stock in bars of a specified length, "short-ends" are eliminated.

After being forged, the hot string of balls is taken to punch presses made by the Ferracute Machine Co., Bridgeton, N. J., which are placed beside the Bradley helve hammers on which the forging operation is performed, the arrangement being clearly shown in Fig. 7. The punch presses are equipped with multiple shearing dies, which consist of a lower die member with holes of the same size as the balls and a multiple punch carried in the ram, one punch being in line with each opening in the die. The string of balls is dropped into place and the

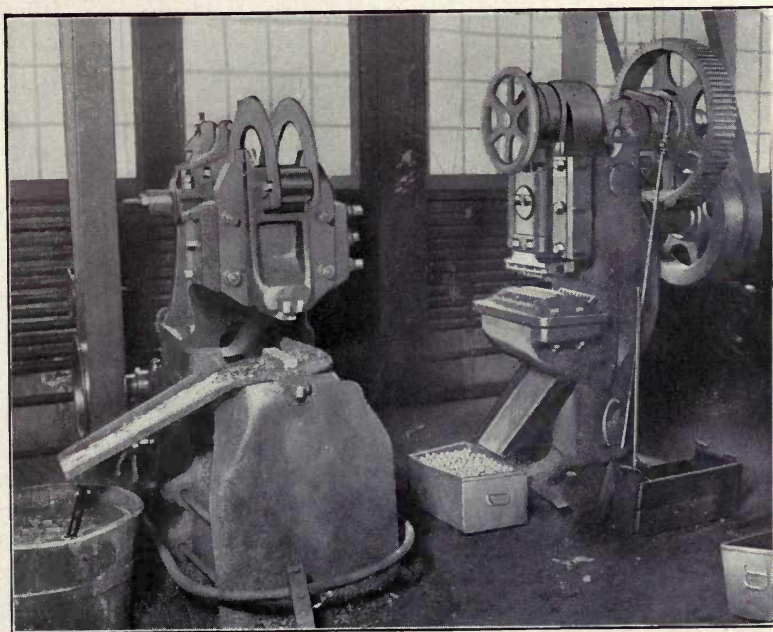


Fig. 7. C. C. Bradley Hammer and Ferracute Power Press in which a String of Ball Blanks is Forged and Cut up into Individual Balls.

press tripped, resulting in pushing the balls through the holes in the die and leaving the scrap metal which is brushed off before the next operation is performed. The bar is then returned to the right-hand side of the heating furnace, as previously mentioned, and is moved to the left each time a heated bar is removed, until it reaches the extreme left ready for another string of balls to be forged from the heated metal at its end. Three sizes of helve hammers made by C. C. Bradley & Son, Inc., Syracuse, N. Y., are used for forging ball blanks, which have capacities for striking blows of 125, 150 and 300 pounds.

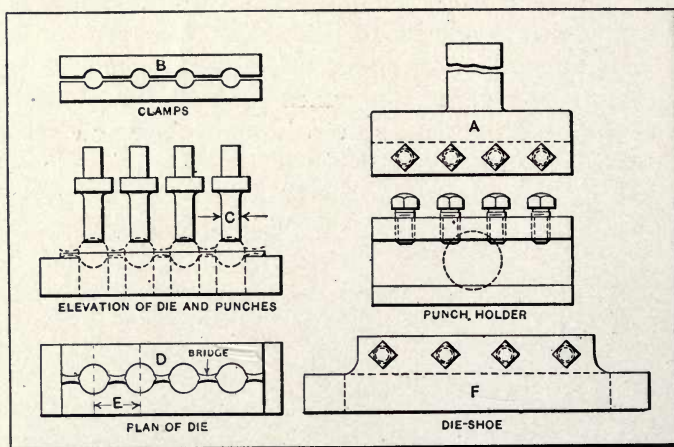


Figure 8. Type of Die used for Shearing String Forgings into Individual Ball Blanks.

Fig. 8. shows the construction of shearing punches used for cutting up the string forgings into individual ball blanks. At A is shown the form of punch-holder used, which will be seen to consist of a cast-iron shoe with four set-screws for holding the punches. These are secured in a clamp B which is made by drilling holes of the proper size for the punch shanks in a block of the desired form and then sawing this block in half; the punches are then put in place and the entire clamp secured in punch-holder A. The diameter C of these punches is usually made about $\frac{1}{8}$ -inch less than the diameter of the balls in the string forging that is to be cut up. A plan view of the die is shown at D, and it will be evident that the spacing E between holes in this die is the same as the center distance between the

die cavities in the forging die. Also a bridge is provided in the shearing die of sufficient depth to retain the neck left between adjacent ball blanks on the string forging while the balls are pushed through the die. After the shearing operation has been completed, the scrap metal is brushed off the shearing die before the next set of ball blanks is cut up.

It has been mentioned that balls ranging in size from $\frac{5}{8}$ -inch up to about $2\frac{1}{2}$ -inches in diameter are made by forging strings of blanks according to the process which has just been described. In the case of the larger sizes of balls—from $2\frac{5}{8}$ to 4 inches in diameter—single blanks are usually forged under a steam hammer, making one blank at a time at the end of the bar. Slugs of the proper size are first cut off to the required length and both ends chamfered, the length of stock being determined by the weight of the finished balls after making a proper allowance for the material removed in finishing. These blanks are placed in the oil furnace and heated to a forging temperature; and each time a blank is removed to be forged a new slug of metal is put into the furnace in its place. Dies used for this kind of forging are of an entirely different form from those used in string forging; they are cupped out to the desired diameter, but are only turned to a depth of one-quarter the diameter of the ball to be forged and are not relieved. When the blank has been heated, the hammer-man places it in the die and the hammer is worked very slowly until the blank begins to take a spherical shape, when quicker and heavier blows are struck. Owing to the shallowness of the die, the operator has ample room to turn the ball in all directions, and he can therefore produce an almost perfect sphere. Blanks up to 8 inches in diameter are forged without varying more than 0.005 inch from a true spherical form.

ROUGH DRY-GRINDING

THE method of making ball blanks varies according to their size, small blanks being made on cold-headers and large blanks forged from hot metal according to the methods which have just been described. After this preliminary work, all sizes of balls go through essentially the same treatment certain minor modifications being made according to the quality of the balls; and the method of treatment may also vary some-

what in the case of balls of extremely large size. These modifications from standard practice will be taken up in detail.

Blanks made by either the cold-heading or hot-forging process are first sent to the dry-grinding room, where they

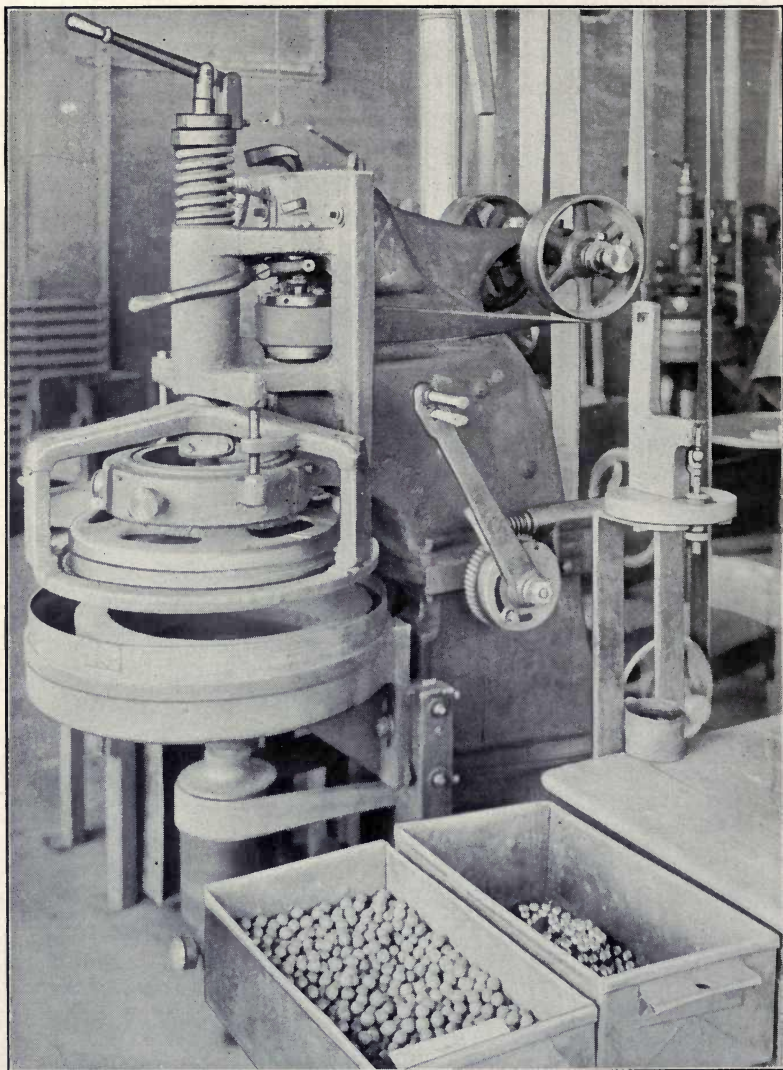


Fig. 9. Side View of Dry-grinder, showing wheel dropped away from work, a Charge of Balls ready to be dropped into Grinding Position, and Ball being measured for Size in Test Indicator.

are subjected to a rough-grinding operation before going to the heat-treating department. This rough-grinding results in removing a considerable part of the surplus metal and bringing each ball to a much closer approximation of a truly spherical form than it is possible to obtain in forgings made by either of the methods that have been described. In the case of hot-forged

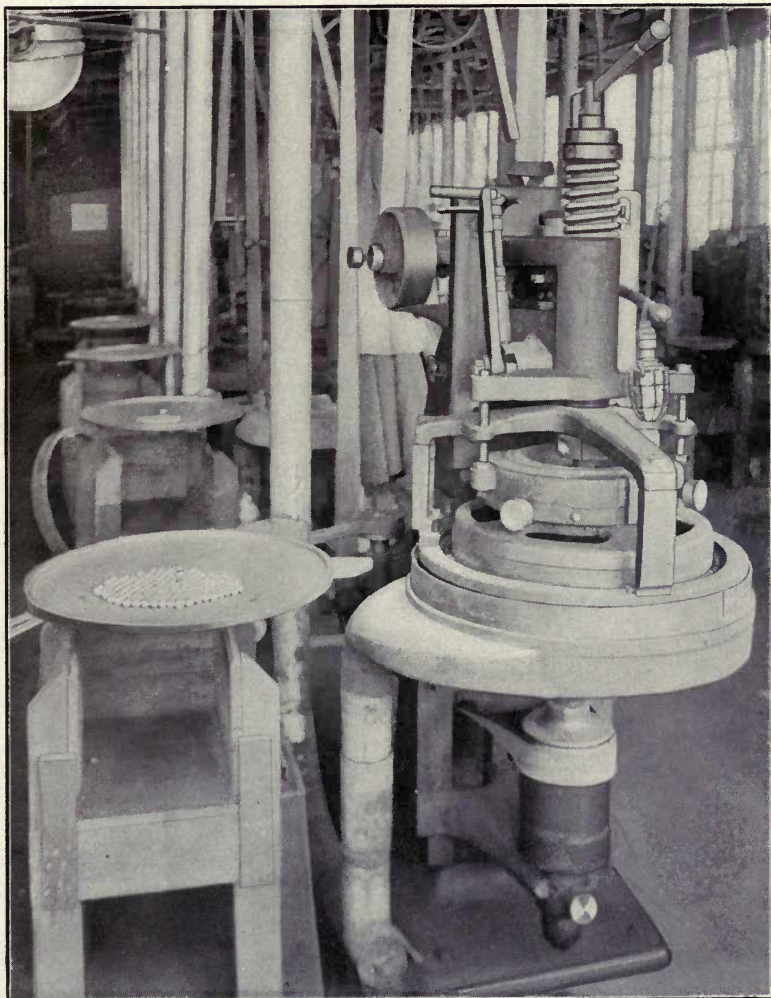


Fig. 10. Front View of Grinding Machine, showing Grinding Wheel raised to Operating Position and Tray of Ground Balls just removed from Machine; Balls seen in Ring are not in Grinding Position

ball blanks, this rough-grinding also removes the decarbonized steel from the surface of the blanks produced in forging.

An exception to the general method of procedure is made in the case of balls from $1/16$ to $3/16$ inch in diameter. Such balls are not dry-ground before being heat-treated, but they get a rough and a finish dry-grinding after being hardened. Figs. 9 to 11, inclusive, show the type of machine on which the dry-grinding operation is performed, and the best idea of its construction and method of operation will be obtained by reference to the two views shown in Fig. 11. The main

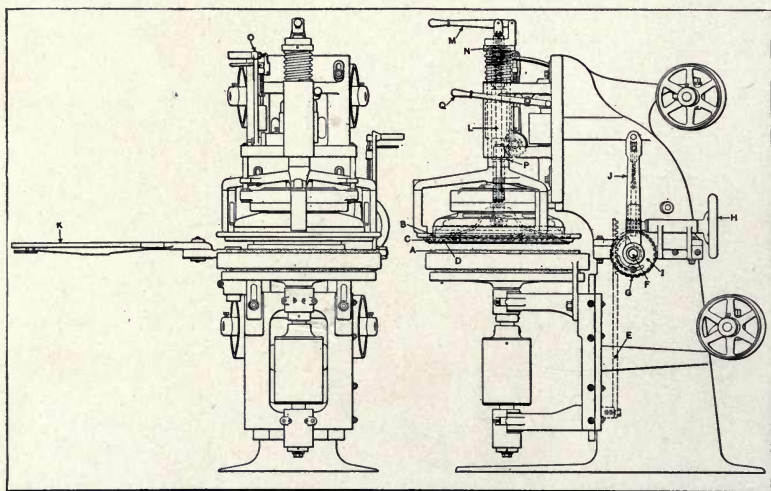


Fig. 11. Front and Side Views of Dry-grinding Machine, illustrating Principle of Operation.

parts of this machine consist of a carborundum grinding wheel *A* and an iron ring *B* which are driven in opposite directions. Two rings *C* and *D* are supported by spiders in such a way that there is a space between the beveled edges of the inner and outer rings sufficient to allow ball blanks that are to be ground to project through this space. In the side view of the machine illustrated in Fig. 11, these rings are shown with the wheel lowered, but when the machine is in operation the balls held between rings *C* and *D* are in contact with grinding wheel *A*; and ring *B* presses down and holds them against the grinding

wheel. In order to provide for grinding the balls uniformly, the spindles on which grinding wheel *A* and driving ring *B* are carried are placed eccentric to each other, which results in giving the balls an oscillating motion in addition to their motion of rotation; and as a result of this combined movement all surfaces of the ball blanks are exposed to the action of the grinding wheel, which results in bringing them to a close approximation of the spherical form. The way in which the upper and lower spindles of the machine are driven is best illustrated in Fig. 9, which shows how open and crossed belts are brought to the machine pulleys from an overhead countershaft.

Probably the best way to describe the operation of one of these dry-grinders is to start at the point where a charge of ball blanks has been ground down to the required size and is to be removed from the machine. To provide for doing this, the head which supports grinding wheel *A* is carried on a slide on the base of the machine. Secured to the bottom of this slide is a rack *E* that meshes with a pinion at the end of cross-shaft *F*. Keyed to the opposite end of shaft *F* is a worm-wheel *G* that meshes with a worm actuated by hand-wheel *H* that provides fine adjustment. Secured to the bed of the machine is a disk *I*, and in order to drop grinding wheel *A* out of contact with the work held between rings *C* and *D*, the spring latch carried by lever *J* is withdrawn from a notch in disk *I* and the lever is moved to the left until the latch engages a stop notch in disk *I*, which limits the downward motion of the grinding wheel. It will be seen that sufficient clearance is now provided between grinding wheel *A* and rings *C* and *D* to enable tray *K* to be swung into position to catch the balls when they are discharged from the holding rings.

It will be seen that inner ring *D* is supported by a spider secured to the lower end of rod *L*, and in order to discharge the ground balls, ring *D* is dropped by pushing down lever *M*. This drops the inner ring and allows the ground balls to fall into tray *K*. When lever *M* is released, ring *D* is returned to its original position by means of a compression spring *N*. During the time that the charge of balls in the machine is being ground, a fresh charge of blanks is placed in the space between driving ring *B* and outer ring *C*; a few of these balls will be seen in position in Fig. 9. After the ground balls have been removed and inner

ring *D* has been returned to the position shown in Fig. 11, it is necessary to place the charge of new blanks in position to be ground. This is done by dropping both rings *C* and *D* sufficiently so that the balls held between outer ring *C* and driving ring *B* may drop into position, after which the two rings are returned to the location shown in Fig. 11. This result is accomplished by means of lever *O* that is carried at the end of a cross-shaft which has a pinion at its right-hand end meshing with the rack *P* cut in the sleeve that supports the spider on which outer ring *C* is carried.

In order to drop a charge of balls into place, the spring latch carried by lever *O* is released and this lever is pulled forward which results in dropping both rings *C* and *D*, due to the fact that rod *L*, supporting inner ring *D*, is pinned to the upper end of sleeve *P*, to which the outer ring is connected by means of the spider. When the balls have been dropped into position as indicated, grinding wheel *A* is raised into contact with the work

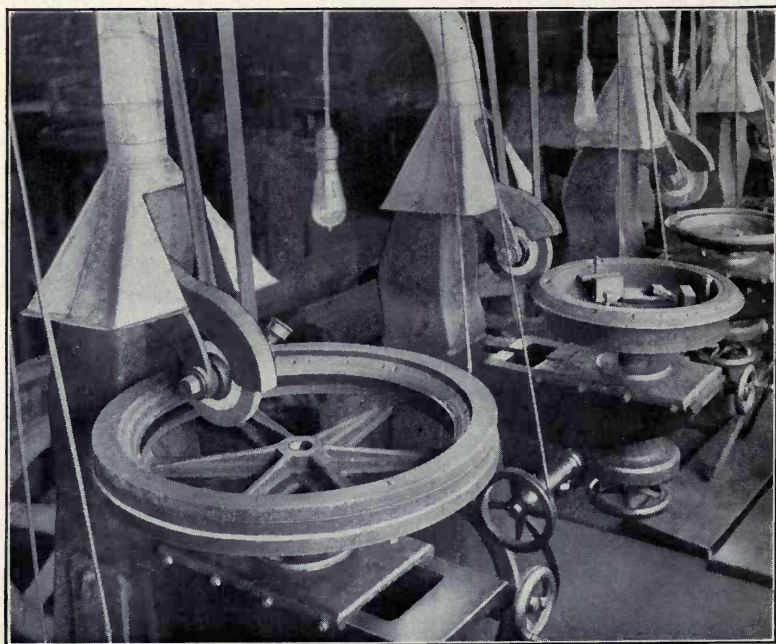


Fig. 12. Special Grinding Machines for Grinding Rings shown at C and D in Fig. 11.

by raising lever *J*. Rings *C* and *D* are ground to a smooth surface and fine edge in order that the balls may run freely and reach through the space to come into contact with the grinding wheel *A*. This is done on special grinding machines, the method of grinding the inner and outer rings being clearly illustrated in Fig. 12. Lever *Q* at the front of the grinding machine operates a clutch that provides for starting or stopping the machine. It will be seen from Figs. 9 and 10 that the grinders are provided with an exhaust system to carry away the dust of the wheel.

HEAT TREATMENT

DURING the process of making the steel for the balls and in forging and rough-grinding the ball blanks made from this steel, severe internal strains are likely to be set up in the metal that would often be of sufficient magnitude to cause the balls to be broken when subjected to only a small

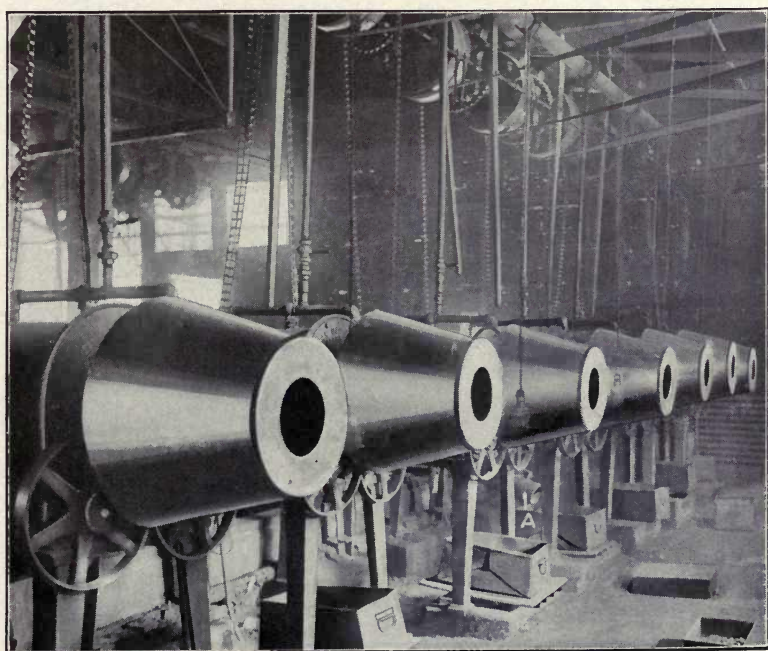


Fig. 13. Charging End of American Rotary Gas Furnaces in which Balls up to One Inch Diameter are Heat-treated.

part of their rated load carrying capacity. Trouble from this source must be eliminated, and this is done by subjecting the balls to a preliminary annealing operation in rotary gas furnaces made by the American Gas Furnace Co. of Elizabethport, N. J., before the final hardening operation. The same type of furnace

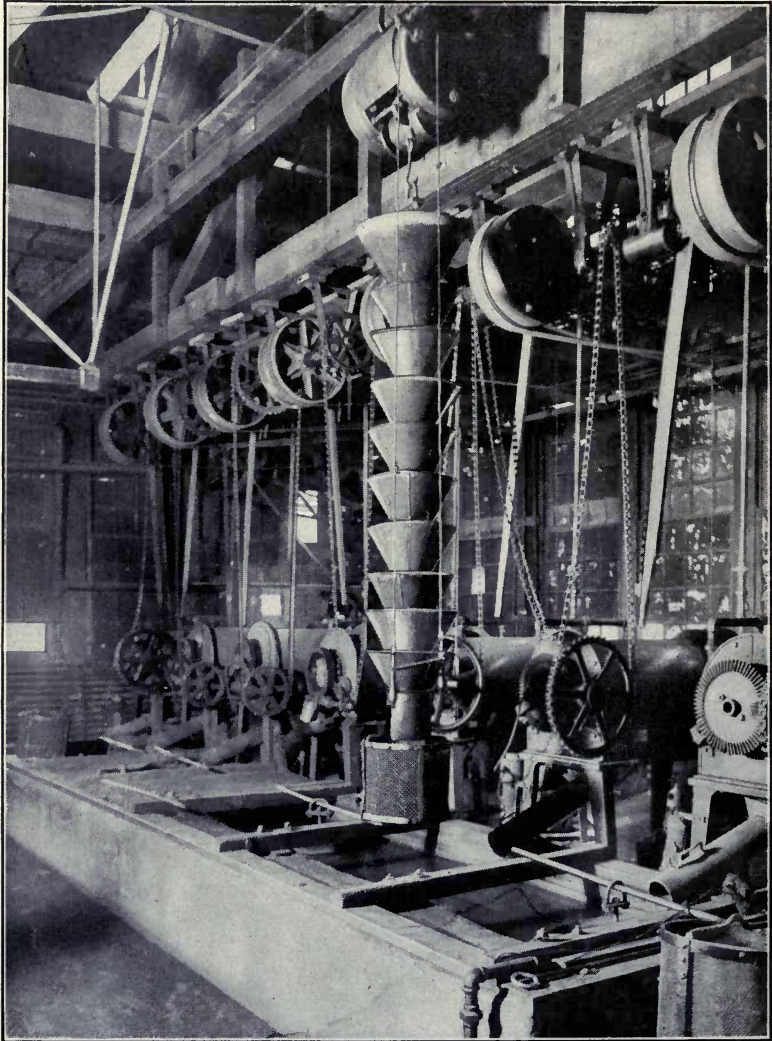


Fig. 14. Discharge End of American Rotary Gas Furnaces, showing Quenching Tanks and Deflector through which Balls are delivered to Baskets at Bottom of Tanks.

is used for the annealing and hardening operations, but for the former the delivery chute on the furnace is arranged to discharge the balls into pans, as shown at *A* in Fig. 13, while for the latter the balls are discharged into a quenching tank, as indicated in Fig. 14. The form of retort used in these American gas furnaces is shown in Fig. 15, and it will be seen to have a spiral path

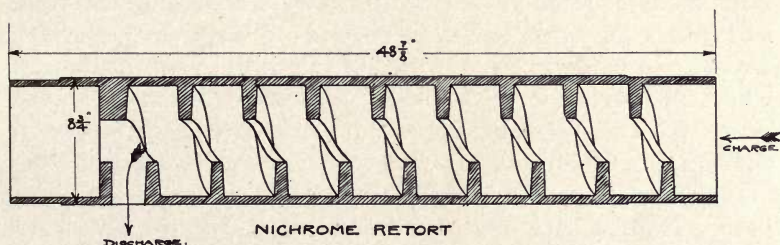


Fig. 15. Cross-Sectional View of "Nichrome" Retort used in Rotary Gas Furnaces.

through which the balls pass as the retort is revolved. At the loading end of each furnace there is a hopper that is kept filled with ball blanks, and the retort draws blanks from this hopper and passes them through the furnace at such a rate that the steel is heated to the desired temperature when the balls are discharged. For annealing, a temperature of 1300 degrees F. is employed, and for hardening the balls are raised to a temperature of from 1425 to 1475 degrees F. according to the size and the composition of the steel. Pyrometers made by the Hoskins Mfg. Co. of Detroit, Mich., are used to determine the temperature of each furnace.

QUENCHING THE STEEL BALLS

IT HAS been mentioned that the same type of furnace is used for both the annealing and hardening operations, the only change being to place the tube so that the ball blanks are discharged into a pan in the case of annealing, and into the quenching tank in the case of the hardening operation. The retorts used in the furnaces were formerly made of cast iron, and great trouble was experienced through their destruction after they had been in service a short time. This trouble has

been over-come by substituting "Nichrome" in place of cast iron, and retorts made of this material last indefinitely.

In hardening, there is a difference of practice according to the size of the balls, those of $5/16$ -inch diameter and less being quenched in oil while balls of larger size are quenched in water. Balls made of some grades of steel are quenched in pure water and others are quenched in brine. In all cases the quenching tanks are provided with a device of the form shown in Fig. 14, which consists of a series of conical sheet metal deflectors through which the balls pass before reaching the wire mesh basket at the bottom of the tank. The purpose of these sheet metal cones is to deflect the course of the balls so that they follow a winding path and are completely cooled before reaching the bottom of the tank. One complete furnace charge can be run into one of these wire baskets and when this is filled, the entire outfit is lifted out of the tank by means of an electric hoist as shown, and the balls are then removed from the basket. The depth of



Fig. 16. "Frankfort" Oil Furnaces for use in Heat-treating Balls over One inch Diameter, and Quenching Tank in which these Balls are Hardened. Note Hoskins Pyrometer for showing Temperature of Furnaces.

the quenching tank is about 14 feet. Rotary furnaces are used for annealing and hardening the smaller sizes of balls, and in the case of balls one inch in diameter and over, "Frankfort" oil furnaces are employed, into which the balls are introduced on trays as shown in Fig. 16. When the balls are heated to the proper temperature, these trays are withdrawn and the balls are dumped into the quenching tanks provided with the sheet metal cones described. The reason for quenching small balls in oil and large balls in water is that the oil does not absorb the heat as rapidly as the water, and in the case of very small balls, the shock of dropping them into water would result in strains so great that many balls would either be cracked or broken, and the strength of those balls in which there were no visible defects would be seriously impaired. In the case of large balls, there is sufficient heat to prevent trouble from this cause. From time to time sample balls are tested by breaking them on an anvil and examining the structure of the steel to make sure that the heat-treatment is producing the desired results. Provision must be made for preventing over-heating of the oil or water in the quenching baths, and this is done by having a circulating system through which the oil or water passes into a reservoir outside the building and then through a coil in this reservoir and back to the tank. In this way the contents of the quenching tank are kept in continual circulation, preventing overheating.

SPECIAL TREATMENT TO RELIEVE INTERNAL STRAINS

DURING the process of hardening, internal strains are set up in the balls, and it is necessary, of course, to relieve the strains without effecting the surface hardness of the balls.

This is done by immersing the balls which are carried in wire baskets, in a tank of boiling water for two hours. The equipment used for this purpose is shown in Fig. 17.

This practice is only followed in the case of balls that are hardened by quenching in water or brine.

Besides relieving the internal strains, the hot water prevents the balls from rusting after their removal, as the hot balls dry off very rapidly.

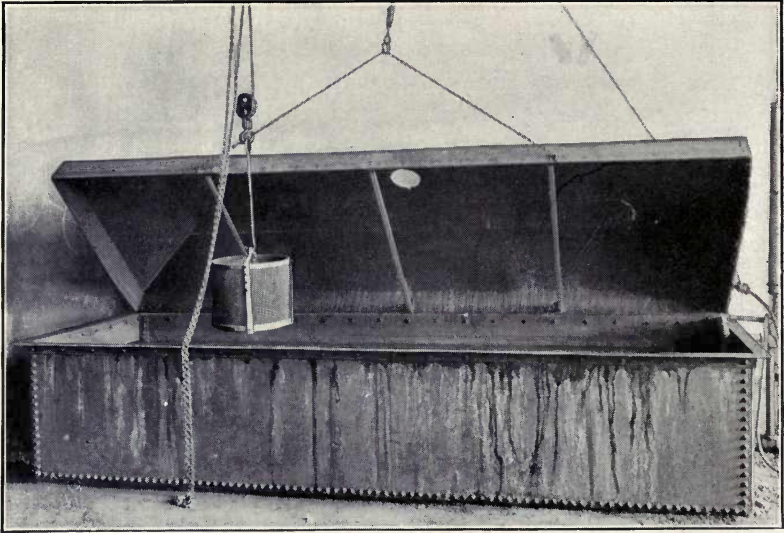


Fig. 17. Water Bath in which Severe Strains are Removed from Balls Quenched in Water by subjecting them to Temperature of Boiling Water for Two Hours. This Treatment also enables Balls to Dry Rapidly and Prevents Rusting.

FINISH DRY-GRINDING

AFTER being hardened, the balls are sent back to the dry-grinding room, where they are subjected to what is known as a finish dry-grinding operation. This is the same as the rough dry-grinding that the balls receive before hardening, except that it is done with a finer wheel which results in removing the scale produced in hardening and also reducing their diameters a little closer to the finished size. For the rough-grinding operation, wheels of No. 40 grit are employed. On the finish-grinding, the grit of the wheel varies according to the size of the balls. Wheels of No. 60 grit are used for all balls exceeding $5/16$ -inch in diameter, while for smaller balls wheels of 90 or 100 grit are employed. In all cases the machines are driven at the required number of revolutions per minute to give a surface speed of 4500 to 5000 feet per minute at the point where the ring wheel engages the balls.

A VISITOR who is conducted through the plant of the Hoover Steel Ball Co. finds it exceptionally easy to become acquainted with what is going on in each shop, because, although the plant is large, it is engaged in making a single product, manufacturing operations on different sizes of balls being conducted in essentially the same way throughout. This condition stands out in marked contrast to that found in plants engaged in the production of a variety of different parts, as the manufacturing operations necessarily vary, making it more difficult to see just what is being done.

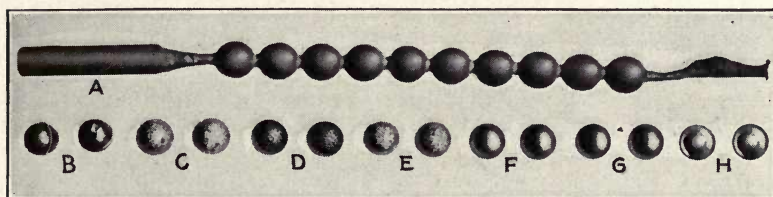


Fig. 18. (A) String of Hot-forged Ball Blanks. (B) Ball Blanks made by Cold-heading Process. (C) Rough Dry-ground Balls. (D) Rough Dry-ground Balls after Hardening. (E) Finish Dry-ground Balls. (F) Oil-rolled Balls. (G) Oil-ground Balls. (H) Polished Balls ready for Inspection.

Fig. 18 shows the condition of the product at each step in the process of manufacture, and it will be of interest to study this illustration carefully, as it shows just what is done to the balls by each operation through which they pass before completion. At *A* is shown a string of hot-forged ball blanks before they have been sheared apart, and at *B* are illustrated two ball blanks made by the cold-heading process. Blanks produced by either of these methods are first subjected to a rough dry-grinding operation which reduces them to an approximately spherical form, as shown at *C*, although the surface is covered with a multitude of small flats and scratches left by the grinding wheel. At *D* are shown two rough-ground blanks after they have been subjected to the process of heat-treatment, and it will be noticed that their appearance is essentially the same as that of the rough-ground blanks shown at *C* except that the surface is darkened as a result of the heat treatment. Two blanks are shown at *E*, which have received the finish dry-grinding after being hardened, and it will be noticed that the appearance of these blanks is the same as that of the rough-

ground blanks *C* except that the flats and scratches are not so pronounced. At *F* and *G* are shown two blanks that have gone through a process known as "oil-rolling" and two blanks that have been through the oil-grinding process. The appearance of both these balls is practically the same except that the oilground balls have been reduced to exactly the desired size. At *H* are shown two finished balls after being polished, ready to be sent on to the inspection department, where they will be subjected to a series of rigid tests.

OIL-ROLLING BALLS IN TUMBLING BARRELS

AFTER receiving the finish dry-grinding, the balls are of approximately spherical form, but the surface is covered with flat spots and scratches left by the grinding wheel and there is still a considerable amount of excess metal on the balls to be removed. The first step is to subject them to a process known as oil-rolling which consists of tumbling a charge of balls in an iron barrel containing oil and abrasive. This oil and abrasive is refuse from machines on which a subsequent operation known as "oil-grinding" is performed; this operation will be

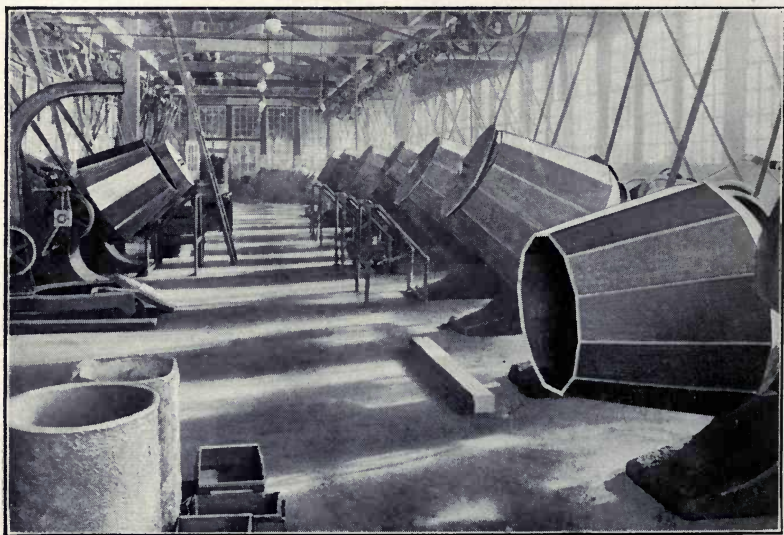


Fig. 19. View in Oil-rolling Department, showing Special Tumbling Barrels of Large Capacity.

described in detail later, and the nature of the abrasive will be explained at that time. Most of the tumbling barrels used in this department have capacity for a charge of 1500 pounds of balls, and these were built especially for the Hoover Steel Ball Co.; but some 800-pound barrels made by the Baird Machine Co. of Bridgeport, Conn., are also employed. Some of these barrels are shown in operation in Fig. 19. The purpose of oil-rolling is to smooth off the flats and scratches left by the dry-grinders and to remove excess stock, about 0.004 inch being allowed for removal in the oil-grinding operation. Balls up to 1½-inch in diameter are given this oil-rolling treatment.

It is necessary to leave the balls in these tumbling barrels from twenty to thirty-six hours, according to the amount of stock that must be removed, and as each ball rotates in such a way that its entire surface is uniformly exposed to the action

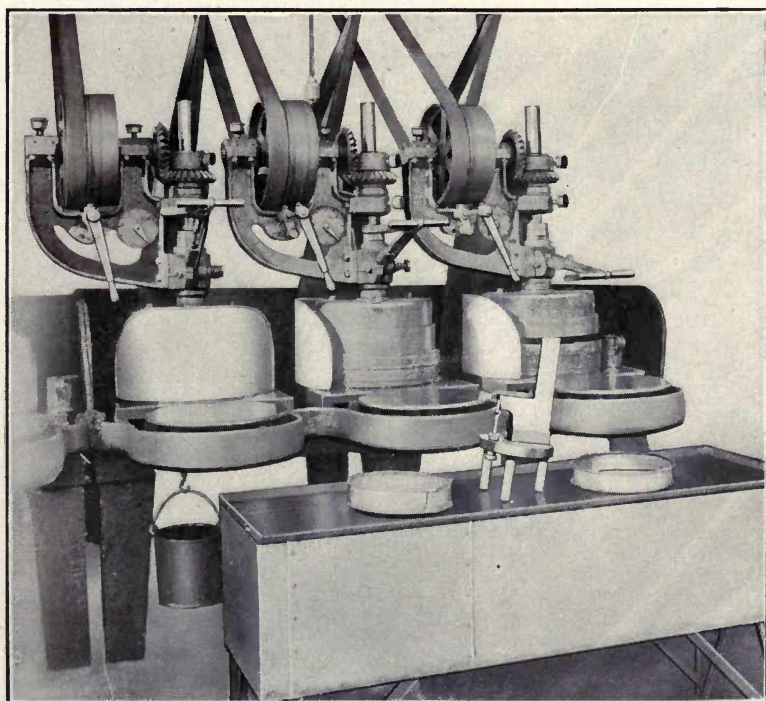


Fig. 20. Oil-grinding Machine on which Final Grinding Operation is performed
—Attention is called to Dials showing Approximate Time when Grinding will be Finished, and Indicator for Testing Size of Balls.

of the abrasive and of the balls adjacent to it, this treatment results in the production of perfect spheres. When the time has almost arrived at which the balls should be removed, a number are selected at random from the contents of each barrel, taken out and measured with a micrometer in order to see how closely they approach the required size. The oil-rolling is then continued with successive gaugings until the balls have been reduced to the required dimension plus 0.004 inch, after which they are removed from the barrels, cleaned, and then taken to the oil-grinding department. In reducing balls by the process of oil-rolling, it occasionally becomes necessary to add more abrasive to the supply of oil and abrasive obtained from the oil-grinders. When this is done, No. 36 carborundum is used, as this coarse-grain abrasive increases the speed at which the balls are reduced to the required size.

HOW THE PROCESS OF OIL-GRINDING IS CONDUCTED

THERE are two main grades of balls made in the Hoover factory, known as "Micro-chrome" and "Commercial" balls, the former being the better quality. Both grades are reduced to the final size by the process known as "oil-grinding" that is conducted on machines of the form shown in Figs. 20

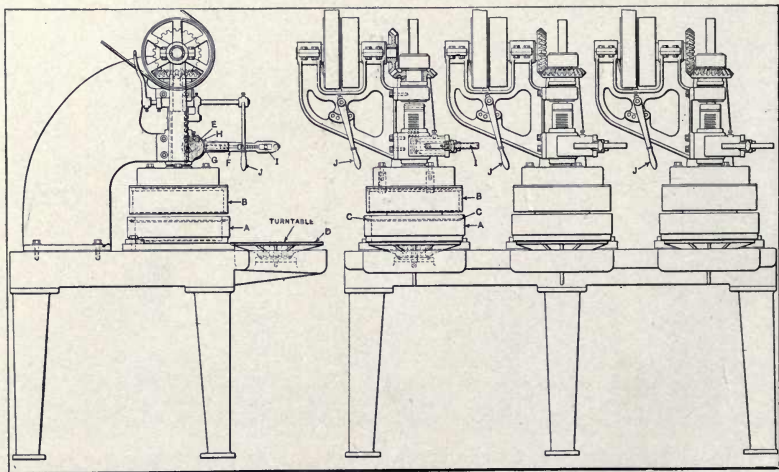


Fig. 21. Side and Front Views of Oil-Grinding Machine, Illustrating Method of Operation.

and 21. The construction and operation of the oil-grinding machines will be best understood from Fig. 21, which shows details of its construction. These machines are provided with two iron rings *A* and *B*, each of which has an annular groove cut in it of a suitable size to accommodate the balls *C* to be ground. It will be noted that there is a small groove at the bottom of the annular groove in the lower ring *A*, which provides for holding a supply of oil and abrasive. Ring *A* has the annular groove for the balls cut at the bottom of a larger groove, and ring *B* has a flange in which the ball groove is cut that drops into this large groove in ring *A*; the arrangement will be readily understood from the illustration. It will, of course, be understood that the grinding ring is filled with balls, the number that constitutes a complete charge varying according to the size of balls that are being ground.

To provide for loading and unloading the machine, lower ring *A* is drawn out onto a table *D* which is provided for that purpose, and after a fresh charge of balls has been put in place this ring is pushed back into position under the upper ring *B* that is secured to the spindle of the machine. A sheet metal shield is then pushed into place in front of the rings in order to prevent splashing of the oil. Ring *A* is located in approximately the desired position by means of a hole in the machine bed into which an extension on the under side of ring *A* drops, but the extension on this ring is a loose fit in the hole to allow ring *A* to align itself properly with ring *B*.

The upper ring is secured to the spindle, and in order to start the grinding operation it must be lowered into contact with the balls carried in the annular groove of ring *A*. This is accomplished by a rack on the spindle sleeve that meshes with pinion *E* secured to lever *F*.

In order to raise ring *B* out of contact with the work so that ring *A* may be drawn out onto turntable *D*, lever *F* is pulled down into the horizontal position shown in the illustration. In this position spring latch *G* drops into a notch on ring *H* that is secured to the frame of the machine, thus holding ring *B* in the suspended position. After the machine has been reloaded and it is desired to drop ring *B* into contact with the work preparatory to starting the grinding operation, spring latch *G* is withdrawn

from the notch in ring *H* by pulling back grip *I* that is connected to the end of the rod on which latch *G* is carried. Then the wheel is lowered by gravity, care being taken to hold tight to the crank at the end of lever *F* so that it is slowly raised to a vertical position instead of flying up and allowing ring *B* to drop heavily onto the balls carried in the lower ring.

It will be seen that there are three grinding heads provided on each machine, and these are furnished with independent tight and loose pulley drives, so that any head may be stopped without interfering with the operation of the other two. This is done by throwing the belt from the tight to the loose pulley by means of lever *J*, which actuates the belt shifter. The oil-grinders are provided with a dial similar to that of a clock, so that the time for grinding can be observed; the grinding operation usually takes from twenty to forty-five minutes, according to the size of the balls and the amount of stock that must be removed. When the machine is set up ready to start the grinding operation, this dial is set to the approximate time at which the grinding operation will be completed, and a little while before this time is reached several balls are selected at random from different points around the ring, and are measured with an indicator to see how near they come to the required size. The dials on the machine and the test indicator are shown in Fig. 20.

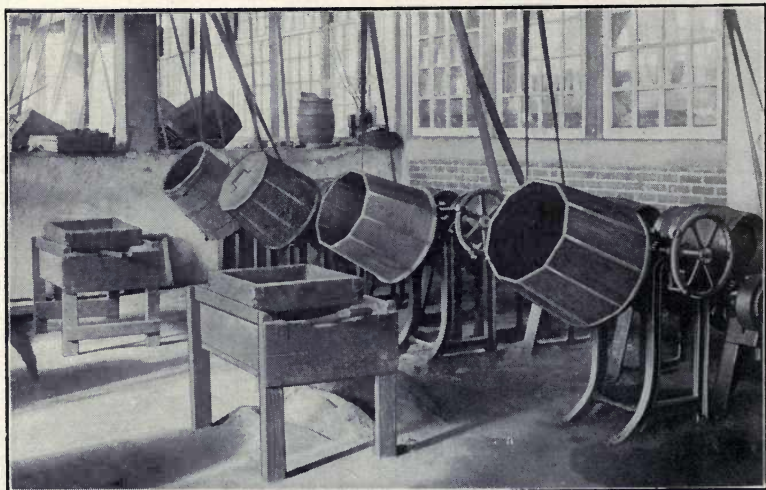


Fig. 22. Small Tumbling Barrels for Cleaning Balls in Sawdust, and Riddles for Separating Sawdust from Balls.

CLEANING AND POLISHING OIL-GROUND BALLS

AS SOON as the balls have been ground down to the desired diameter, they are removed from the machine and taken to tumbling barrels containing hardwood sawdust, in which they are rolled for a sufficient length of time to clean off all oil and abrasive. The charge in each tumbling barrel is then taken out and put into riddles through which the sawdust is sifted, as shown in Fig. 22, to separate it from the balls; the balls next go to the tumbling barrels containing a mixture of oil



Fig. 23. Kegs in which Balls are Polished by Rolling in Leather.

and Vienna lime. They are rolled in this mixture for a sufficient length of time to give them a preliminary polish, after which they are removed and again cleaned in tumbling barrels filled with hardwood sawdust. The sawdust is sifted from the balls in riddles, after which they are rolled for from twenty to twenty-five minutes in kegs containing strips of kid similar to that from which gloves are made, the arrangement of this polishing equipment being shown in Fig. 23. Rolling the balls in this way gives them a high polish, which is the final step in the process; and the finished balls are then ready to be taken to the inspection department.

The following data concerning conditions under which oil-grinders are operated and abrasives and oils used on these machines will prove of interest. It has been mentioned that two main grades of balls are made, which are known as "Micro-chrome" and "Commercial" the former being the better quality. On the "Micro-chrome" balls the grinders are run at 195 revolutions per minute and the abrasive used is a mixture of No. 3-F carborundum and "Atlantic Red" machine oil made by the Standard Oil Co. On "Commercial" balls, the grinders are run at a speed of 325 revolutions per minute and the abrasive is an equal mixture of Nos. 180 and 150 carborundum to which No. 4 "Road Oil" is added, this oil also being the product of the Standard Oil Co. Used oil and abrasive from the grinding machines is collected and used in the tumbling barrels.

SPECIAL TREATMENT FOR LARGE BALLS

CERTAIN variations from the practice described in the preceding paragraphs are necessary in the case of large sized balls which would be too heavy to handle in tumbling barrels. For instance, "Commercial" balls over $1\frac{1}{2}$ -inch in diameter and "Micro-chrome" balls over $\frac{5}{8}$ -inch in diameter are burnished on oil-grinders running at high speed and in which very fine abrasive and light oil are used instead of being subjected to a tumbling operation in barrels containing a mixture of oil and lime, as previously described. If large balls of this kind were put in a tumbling barrel, there would be too much shock from the balls striking one another; hence the variation in practice.

PRODUCTION OF OIL-ROLLED BALLS

IT HAS been explained that in the regular process of manufacture the balls go from the tumbling barrels to the oil-grinders on which they are reduced to the required size ready for polishing. There are some cheaper grades of balls, however, that do not go to the oil-grinders; these balls are reduced to size by oil-rolling in the tumbling barrels, after which they are polished and sent to the inspection department. The method of polishing is the same as that to which the better grades are subjected, which was previously described. In oil-rolling the balls, a mixture of No. 36 carborundum and No. 4 "Road Oil" is used in the tumbling barrels.

MANUFACTURE OF BRASS, BRONZE AND COPPER BALLS

IN ADDITION to its regular product, the Hoover Steel Ball Co. does quite an extensive business in the manufacture of brass, bronze and copper balls of various sizes. One important use of these balls is for various forms of valves, although they find a number of other applications. The general features of the methods used in producing these balls are the same as those employed in making steel balls, but there are certain modifications which will prove of interest. Brass, bronze and copper ball blanks up to $1\frac{1}{4}$ -inch in diameter are produced on Manville cold-headers, and blanks for balls exceeding this size are cast. In the case of very large balls the practice is often adopted of making the blanks hollow, which is done by casting them with a sand core that is subsequently removed. Then in order to prepare the blank for finishing, the holes left by the core prints are drilled, reamed and tapped so that threaded plugs may be screwed in. These hollow ball blanks are then subjected to the regular process of manufacture, and it is a difficult matter to detect the place where the plugs have been screwed in.

As in the case of steel balls, these blanks are first subjected to a process of dry-grinding to make them approximately spherical. Brass, bronze and copper balls are too soft to stand treatment in tumbling barrels, as they would be covered with bruises from impact with each other. After being dry-ground, they receive

the regular process of oil-grinding and are then polished in machines of the same design as those used for oil-grinding; but in polishing, the balls are rolled in oil without any abrasive, which results in giving them quite a high polish, although the surface produced is not as highly finished as in the case of steel balls which are subjected to burnishing and polishing operations after being oil-ground. In treating brass, bronze and copper balls in the oil-grinding machine, care must be taken not to subject them to too great pressure, and in order to guard against this the rings on the machine are filled with brass and steel balls arranged alternately; the steel balls support the pressure of the upper ring and the head on which it is carried, and allow the balls to be ground and polished without being subjected to sufficient pressure to flatten them.

INSPECTION OF FINISHED BALLS

AFTER each step in the process of manufacture, the balls receive a general inspection to make sure that nothing is wrong with the adjustment of the machines or with the material from which the balls are made that will prevent the production of balls that come up to the standard. After receiving their final polish, the finished balls go to the inspection department, where they are subjected to a number of searching tests in order that all defective balls may be eliminated and that those balls which pass inspection may be divided into various grades according to the accuracy of their dimensions.

The first step is to clean the balls thoroughly, which is done by placing them in metal baskets provided with long handles so that the load of balls may be dipped into gasoline to remove grease and particles of leather carried over from the polishing department. After this washing, the balls are put into canvas bags and rolled on a table so that the bags will absorb the gasoline and wipe off the dirt. The balls are given a preliminary wiping in one of these bags, after which they are placed in a second bag that is cleaner and insures the removal of the last traces of gasoline and dirt.

MAKING PLATE INSPECTION

AFTER cleaning, the first actual examination is conducted on what are known as "inspection plates," one of which is shown in Fig. 24. These plates are used on benches that run all the way around the two inspection rooms, so that advantage may be taken of the liberal amount of daylight provided by the windows which extend from below the bench up to the ceiling. The plates are made of glass and painted black. A reflector is set up at the back of each inspection plate which throws light on the balls; and a strip of thin flexible cardboard is drawn back and forth beneath the balls to rotate them and bring all surfaces into view. Several times while making this inspection all the balls on the plate are rubbed with a cloth to change their axes of rotation and insure exposing the whole surface. The first step is to pick out balls having cracks, flats, etc., and these are sold as seconds or scraps.

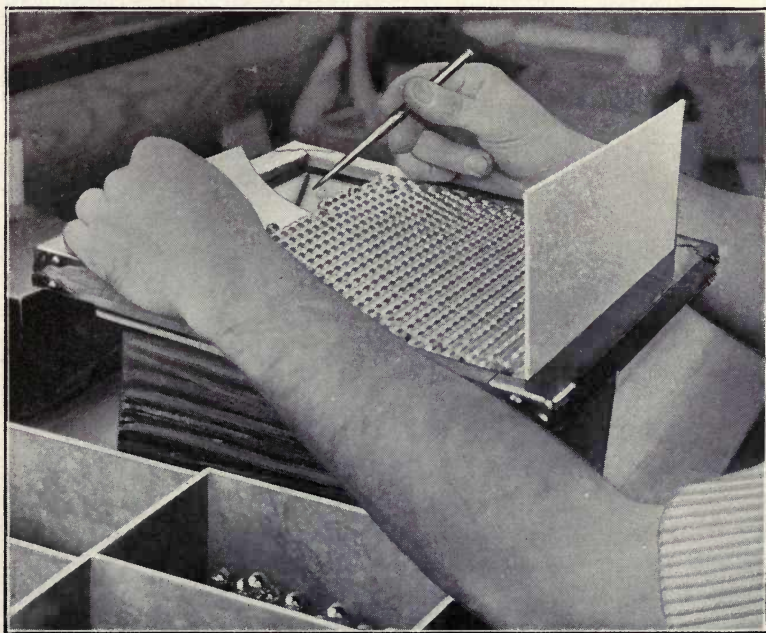


Fig. 24. Type of Glass Plate on which Preliminary Inspection is Conducted.

During the next step in the process of inspection, attention is paid to a white spot on each ball that is thrown from the reflector at the back of the inspection plate. As previously mentioned, a card is drawn back and forth under the plates to make them revolve, and the inspectors first pick out what are known as "wrigglers," which is the name given to balls that are out of round and go through a series of contortions while being rolled. After this has been done, the balls on the plate are gone over carefully and all those that show any defect are picked out. During this process of inspection, the balls are sorted into eight grades, as follows: (1) "Cracked," balls that have received their cracks from any cause, (2) "Junk," balls which have flats, holes, etc.; (3) "Rubbish," same defects as (2) but not so bad; (4) "Dead soft," balls that are covered with small pits caused by impact with hard balls during the process of tumbling; (5) "Out of round," balls known as "wrigglers" by the inspectors; (6) "Fifth grade," balls with small cuts and scratches on them; (7) "Fourth grade," balls showing same defects as "Fifth grade," but not of so serious a character; (8) Balls having no defects sufficiently serious to be visible to the eye. The inspectors engaged in making the plate inspection are provided with small magnets somewhat the shape of a pencil with which they handle the balls with amazing dexterity.

Disposal of the defective balls varies somewhat according to their size. Many of the small balls with defects of the kind referred to are sold to various manufacturers, according to the class of service required of them. For instance, very poor balls are sold to novelty makers. Other balls that are not good enough for use in high-grade ball bearings are plenty good enough for the use of certain manufacturers of hardware specialties, such as roller bearing castors for furniture, roller bearing roller skates, etc. Large balls that are found defective are returned to the manufacturing department, where they are ground down to a smaller size in order to remove the defects from the surface of the metal; and these balls are again carried through the regular process of manufacture.

GAUGING BALLS FOR SIZE

BALLS that are used in annular bearings must be of absolutely the same size in order to give satisfactory results.

If this is not the case, the large balls will support all the load, and the undue amount of service to which they will be subjected will cause them to be destroyed more rapidly than would otherwise be the case. In order to fit properly in the races, it is desirable for the balls to be of exactly the specified size, but provided all the balls are of the same size, they are capable of giving very satisfactory results even though they are either slightly over or under the specified size. In the final process of inspection, the balls are gauged and sorted out into different grades, according to whether they are of exactly the specified size or somewhat under or over this size. Attention is called to the fact that this variation in high-grade steel balls does not exceed a few ten-thousandths inch. As balls of the different grades are all of the same size, they are capable of giving perfectly satisfactory results. Some users of balls gauge them at their own plants and make this sub-division, while others buy gauged balls ready for assembly.

In gauging those balls which show no defects in conducting the plate inspection, practice varies according to the size of the balls, but in all cases the object is the same, namely, to sort the balls out into those which are of absolutely the desired size and those which vary by different degrees either above or below the standard. Balls up to and including $\frac{5}{8}$ -inch in diameter are gauged on automatic machines which sort them into seven different grades, as follows: balls exceeding 0.0002 inch over size; balls 0.0002 inch over size; balls 0.0001 inch over size; balls of the specified size; balls 0.0001 inch under size; balls, 0.0002 inch under size; and balls more than 0.0002 inch under size. Automatic gauging machines are used for this grading, two batteries of such machines being shown in Figs. 25 and 26. The balls are placed in hoppers A, at the bottom of each of which there is a plate in which a number of holes are drilled in a ring, these holes being of slightly larger size than the balls to be gauged. The plates are revolved, and as each hole comes into line with the delivery tube, the ball carried in this hole drops into the



Fig. 25. Close View of Battery of Automatic Gauging Machines with Inclined Blades.

tube and runs down over gauge blades *B* which are set at a slight angle to each other so that balls of the different sizes referred to will drop between the gauge blades and enter tubes that carry them to the proper drawers in the cabinets beneath.

It will be seen that two types of machines are shown in Figs. 25 and 26. In Fig. 25 the gauge blades are placed on an incline so that the balls run over them by gravity, and as the balls are always in contact with the gauge blades, the tubes leading to the drawers of the cabinet can be placed much closer together than on the type of machine shown in Fig. 26, where



Fig. 26. Close View of Battery of Automatic Gauging Machines with Horizontal Blades.

the gauging blades are in a horizontal position. On the latter type of machine an agitator is necessary to keep the balls moving over the gauge blades. This agitator consists of a crank *C* and connecting-rod *D* that actuates a link mechanism which causes a horizontal bar to rise in the space between the gauging blades. This bar rises slightly and then moves forward, carrying the balls with it, after which the agitator bar slowly drops and leaves the balls once more supported on the gauging blades. In

this way the balls are moved along over successive tubes and finally drop through between the gauging blades—the position being determined by the size of the balls—so that different sizes of balls are sorted out as previously described. A stop checks the progress of the ball as it passes onto the gauging blades, and prevents it from rolling too fast. The gauging blades are set by master balls, in order to have the desired angle between them; and before the balls are packed, the accuracy of the blade setting is tested.

SPECIAL INDICATOR FOR TESTING BALLS

FOR gauging balls larger than $\frac{5}{8}$ -inch in diameter use is made of an instrument of the form shown in Fig. 27. This will be seen to consist of an ordinary Brown & Sharpe dial test indicator accurate to 0.0001 inch, that is set

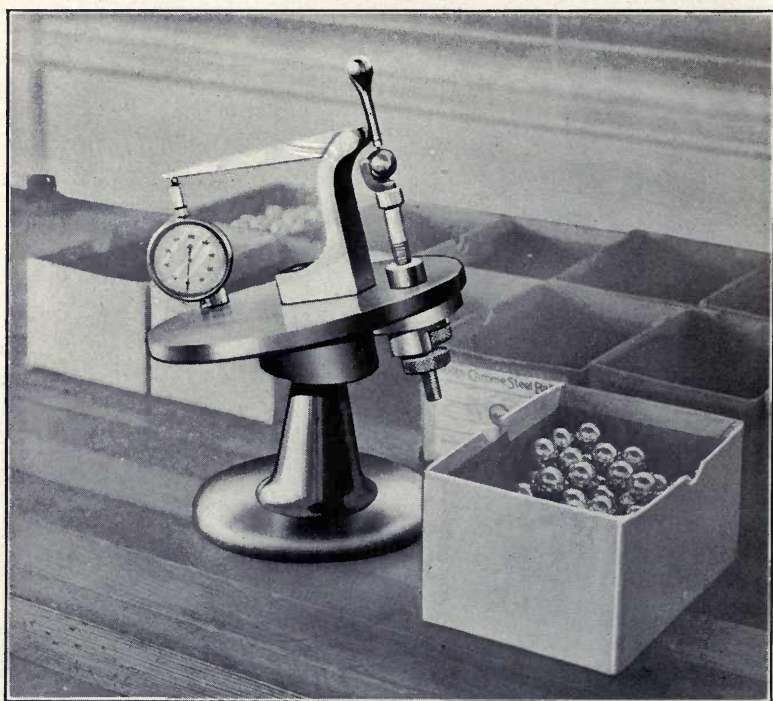


Fig. 27. Dial Indicator with 10 to 1 Leverage Ratio, for Testing Accuracy of Balls to 0.0001 Inch.

up on the table on which is also carried a holder for the ball to be tested. Connection between the ball and the dial test indicator is made by a lever, the fulcrum of which is so placed as to give a ratio of 1 to 10, and in this way readings obtained are accurate to 0.0001 inch. The girls who conduct this inspection handle the balls very rapidly and sort them out into different sizes according to the amount of deviation from the normal size.

COUNTING AND PACKING BALLS

IT IS necessary to use great care in handling finished balls to prevent them from becoming rusty. On this account it would not do to have the balls touched by the fingers. For these reasons, several methods of mechanical counting have been developed which give extremely satisfactory results. The apparatus used for this mechanical counting is shown in Fig. 28. The balls are placed in hopper *A* and dropped down in holes in sliding plate *B*, which is pushed forward so that the holes are under the hopper during the "loading"

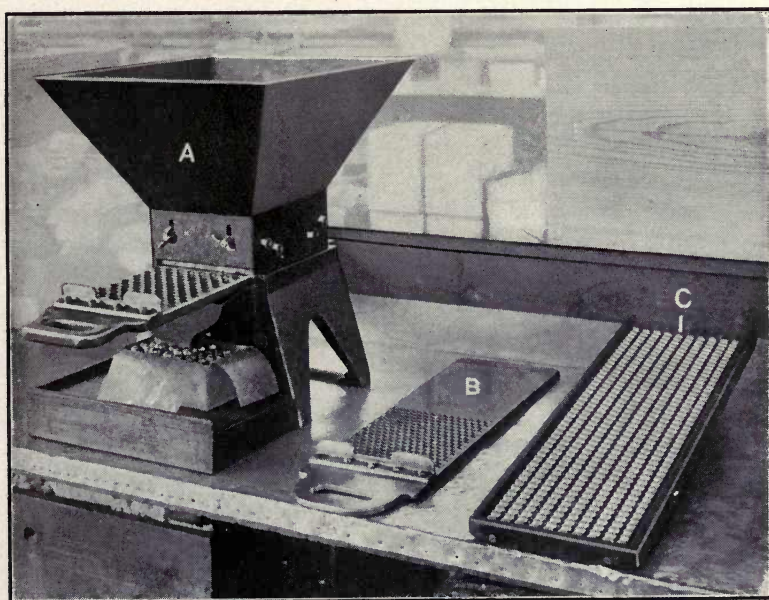


Fig. 28. Methods used for Counting Balls Preparatory to Packing.

period. The plate is then drawn forward to allow the balls to drop out into a box placed to receive them. Each stroke of the plate counts out one hundred balls, and plates for counting balls of various sizes are made interchangeable so that all of them may be used on a given machine. Balls up to $\frac{1}{2}$ -inch in diameter are counted by the machine, and balls from $\frac{9}{16}$ to $\frac{7}{8}$ -inch in diameter are counted mechanically by means of board C, into the grooves of which the balls are loaded up to an index line. Plates of this kind are made for various sizes of balls, and each plate holds 500 balls. Large balls are counted by hand, care being taken not to touch the balls with the bare fingers. After counting, the balls are packed in cartons lined with waxed paper, and these are packed in substantial wooden boxes for shipment.

RESEARCH DEPARTMENT

IT IS obvious that in the tonnage manufacture of a product that must meet such exact requirements as balls for use in high-grade annular bearings, the greatest care must be taken in the selection of raw material and in conducting each step in the process of manufacture in order to produce balls that will pass the inspection department. In addition to the requirements of high-grade balls that were referred to in the description of various examinations that are conducted by the inspectors, it is absolutely necessary for the balls to be of uniform hardness and strength because this is the only way of being sure that all balls will possess the necessary durability and elasticity.

Assurance must be obtained that the steel received at the factory is of a suitable grade to produce balls that will fulfill the specifications before manufacturing operations are started, because if the balls were finished before it was found that they were defective, the raw material and the labor involved in converting this material into finished balls would be lost. Data showing that the steel fulfills these specifications are obtained from the results of tests conducted in the testing department which is equipped with all the necessary apparatus for making physical and chemical tests upon the raw material. In addition, this department is referred to by heads of the various manufac-

turing departments when any case of trouble arises, such as failure of the balls to harden properly, the production of more than the usual number of balls with cracks, and other troubles of this kind. Some exceptionally interesting facts have been brought to light as the result of work conducted in the metallurgical department and chemical laboratory.

TESTING RAW MATERIAL

THERE are sidings from the Ann Arbor Railroad entering the plant so that cars may be run directly to the building in which the raw material is received and to the building where the finished balls are packed for shipment. The method of procedure in testing raw material is the same for both bar stock and coil, and consists of taking at random a number of each kind in proportion to the quantity received and from the end of each of which is cut a sample. One end of this sample is etched in dilute hydrochloric acid for fifteen minutes. After this has been done, the surface of the metal is carefully examined to see that it is free from seams. The acid tends to accentuate any surface defects that may be present, so that those that might be invisible in the bar as it comes to the plant can be quite easily seen after the treatment. In ball manufacture it is highly important for the stock to have a flawless surface, because any slight defects are carried right through the process of manufacture and are likely to become accentuated, with the result that balls produced from this stock will be rejected by the inspectors.

The regular routine tests of the raw material inspected in the laboratory also include a Brinell hardness test. This is especially important in the case of "wire" under 11/16 inch in diameter that is converted into ball blanks by the cold-heading process, because excessive hardness of this material is likely to give trouble through the breakage of the cut-off knives or the dies used on the cold-headers. In order to give the best possible results, stock for the cold-heading machine should have a Brinell hardness of not over 170. A sufficient number of samples to represent the average uniformity of the shipment are examined for pipes, segregation or decarbonization, and when

necessary microphotographs are made, which together with their accompanying reports, put definitely on record the condition of each shipment. Samples are also taken for chemical analysis from each shipment and the percentage of the most important elements determined, this being influenced by the kind of material received and the effect of these elements on the finished product. In cases where laboratory tests do not show that the stock is defective, an "unloading ticket" is made out and sent to the stock-room, authorizing the material to be taken from the cars and placed in storage, ready to be drawn out on requisition by the manufacturing department.

On the following pages are given our specifications for coil and bar stock, and a consideration of these will show the care taken in the selection of raw material used in the manufacture of Hoover steel balls.

HOOVER STEEL BALL CO.

SPECIFICATION NO. 1.

Chrome-Carbon Steel Wire—Cold Drawn.

ANNULMENTS:

1. This specification supercedes all previous specifications, or letters of instruction, covering this material.

MANUFACTURE:

2. The material must be made by the Electric or Crucible process.

QUALITY:

3. The material must be of highest quality in every respect, of uniform composition, and free from slag or other segregation.
The wire must be free from imperfections, such as pipes, seams, checks or laminations either on the surface or in the section of the wire.

WORKMANSHIP AND FINISH:

4. The wire must be of good workmanship, must have a good surface finish, and must be true to diameter ordered within the limits of plus .002" and minus .002".
If the wire is out-of-round, the mean of the largest and smallest measured diameter must be equal to the size ordered, but in no case can they exceed the limits of plus .002" and minus .002".

COMPOSITION:

5. Upon receipt of the material at destination, drilling may be taken from the several coils, selected at random, for analysis, and must show the composition of the material to be uniform and within the following requirements.

Carbon	.95 %	to	1.05 %
Chromium	.35 %	to	.45 %
Manganese	.30 %	to	.45 %
Silicon	.20 %	to	.35 %
Phosphorus under	.025 %		
Sulphur under	.025 %		

CONDITIONS:

6. The material must be thoroughly and uniformly annealed and the fracture must be close grained.

The Brinnell hardness (5 m/m Ball under 1000 Kg. pressure) must not exceed 170 at any point in the length or any point in the cross section of the wire, so that when blanks made therefrom are cold upset into the form of a Ball, no defects will open up in the outside surface of the Ball.

The wire must be free from any decarbonized surface and after hardening must show a close grained velvety fracture.

COIL SIZE, WEIGHT AND CONDITION:

7. Coils must be reeled uniformly and the layers must be bound together securely with separate tie wires to keep them in good shape during transportation so that they can be unwound properly without tangling. If the ends of the coil are tapered down or imperfect in any way, they must be "cropped" off.

Coils may be covered with a coating of oil or grease to protect them from excessive rusting during transportation, but the coils must be free from any hard or gritty foreign matter that would interfere with their proper operation in the heading machine.

The coils must not be less than 18" inside diameter or greater than 34" outside diameter. Wire of heavy cross section should be wound in as large a coil as possible, but within the outside diameter limit given above.

The coils should weigh not less than 90 pounds or more than 110 pounds for wire above .235" diameter. Coils of wire below .235" diameter may weigh as low as 70 pounds.

REMARKS:

8. Material which fails to meet the above requirements will be rejected and returned. The manufacturers must pay all transportation charges on rejected material.
Ann Arbor, Mich., January 1st, 1917.

HOOVER STEEL BALL CO.

SPECIFICATION NO. 5.

Chrome-Carbon Steel Bars—Hot Rolled.

ANNULMENTS:

1. This specification supercedes all previous specifications or letters of instruction covering this material.

MANUFACTURE:

2. The material must be made by the Electric or Crucible process.

QUALITY:

3. The material must be of highest quality in every respect, of uniform composition, and free from slag or other segregation.
The bars must be free from imperfections such as pipes, seams, checks or laminations either on the surface or in the section of the bar.

WORKMANSHIP AND FINISH:

4. The bars must have as good a surface finish as is consistent with good hot rolling practice. They must be free from excessive scale, and must be true to diameter ordered within the following limits.

Minus 0 and plus .005" for sizes under 13/16" diameter.

Minus 0 and plus .010" for sizes over 13/16" diameter.

If the bar is slightly out-of-round, the mean of the largest and smallest measured diameter must be within the minus and plus limits given above.

Appended to this specification is a table giving the prevailing sizes (diameter) of stock which we use, and the corresponding decimal sizes. We reserve the right to change this list from time to time when necessary but the order or contract calling for the material will specify the size wanted.

As an example, if our order calls for 13/16" plus .010" (Decimal .823"), the manufacturer may supply this as large as .833" diameter but no smaller than .823" Diameter.

COMPOSITION:

5. Upon the receipt of material at destination, drillings may be taken from the several bars, selected at random for analysis, and must show the composition of the material to be uniform and within the following requirements.

Carbon	.90 %	to 1.00 %
Chromium	.60 %	to .70 %
Manganese	.30 %	to .45 %
Silicon	.20 %	to .35 %
Phosphorus under	.025 %	
Sulphur under	.025 %	

CONDITIONS:

6. The material must be thoroughly hot-worked to produce a fine grain and must not, subsequent to this hot working, be subjected to a high temperature such as would produce a coarse grain.

The surface of the bars must be free from decarbonization to the extent that upon removing .005" from the diameter of the bar, the remaining section will retain its full quota of carbon as called for under composition.

The bars must be cut to uniform lengths as ordered. A preferred length will be specified on the order, also a minimum length and a maximum length, but in no case may intermediate lengths be supplied. For example, a 13/16" plus .010" diameter bar will be ordered cut to lengths 64", 73" and 82" with 73" as the preferred length.

SHIPPING:

7. When two or more different sizes are shipped together in the same car, they must be so arranged and located in the car that they will not become mixed during transportation.

REMARKS:

8. Material which fails to meet the above requirements will be rejected and returned. The manufacturers must pay all transportation charges on rejected material.
Ann Arbor, Mich., January 1st, 1917.

TESTS OF SEAMY COLD-DRAWN WIRE

IN DESCRIBING the inspecting of balls, reference was made to the rejection of those in which cracks are found. These exist almost entirely in balls up to and including $\frac{5}{8}$ -inch in diameter, the blanks for which are made by the cold-heading process; it seldom happens that cracked balls are found in sizes over $\frac{5}{8}$ -inch, blanks for which are made by the process of hot-forging. A study of this subject reveals the fact that after cold-heading, ball blanks very often had some sort of crack, and in a great many cases these were quite deep. At first it was thought that this was due to faulty annealing or to some element in the steel, which had a tendency to make the metal brittle, but subsequent investigation showed that this was not the case.

STUDY OF SEAMS IN STEEL BARS AND WIRE

DEFFECTS revealed by etching the metal in dilute hydrochloric acid run lengthwise of the bar; sometimes these extend for the entire length of the coil, while in other cases only one end is found to be defective. For want of a better name, the laboratory has called these defects "seams," and it has been proved that wire with seams will in all cases be split to some extent during the process of cold-heading, while that without seams will produce perfect balls in the cold-heading machines. In some cases the cracks opened up in the balls while cold-heading are not so deep that they cannot be eliminated during the subsequent treatment to which the blanks are subjected; but in other cases it may happen that these splits in the blanks are so deep that they reach below the surface of the finished balls, in which case the balls will be rejected by the inspectors.

The investigation conducted in the laboratory relative to troubles resulting from stock having seams or scratches have developed the following information: (1) Cold-drawn wire on which the surface is apparently quite smooth, and on which no seams are visible, is found in many cases to possess minute laps or seams which are made visible by etching with dilute

hydrochloric acid. (2) Although these seams may not be deep on the original wire, they are accentuated by the stretch which the surface of the wire undergoes during the cold-heading operation. (3) Such cracks are likely to be still further accentuated in hardening, and in many cases they will cause the ball to split in half.

In making a study of the effect of seams on the steel, it is the practice, as previously mentioned, to etch the stock with dilute hydrochloric acid for fifteen minutes.

The action of the acid first lays open any surface defects which may be closed so tightly by the pressure of the cold-drawing operation that they will be invisible to the eye unless subjected to the acid treatment. The acid also makes the cracks black, and subsequent grinding exposes the white surface of the adjacent metal so that the crack is brought into as great prominence as possible.

TESTING FOR SEAMS IN STOCK BY APPLICATION OF PRESSURE

RECENTLY another test for revealing these seams has been developed, which consists of upsetting short blanks cut from the bars. These test blanks for wire having a diameter of .275", are 7/16-inch high and are ordinarily

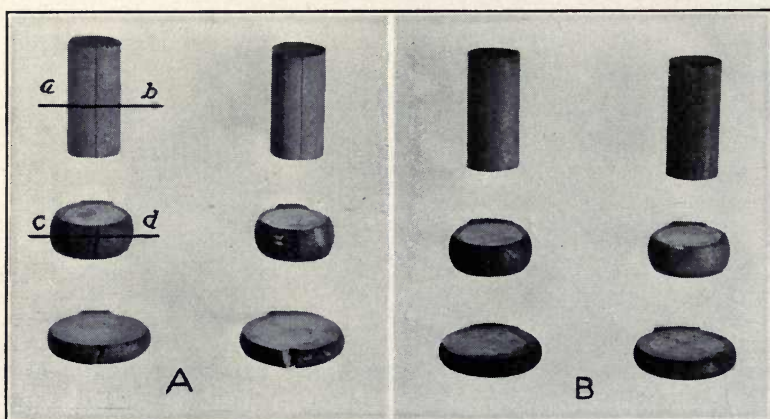


Fig. 33. (A) Samples cut from Steel with Seam in Surface, and Same Samples partially and fully upset, indicating how Seam opens up through Application of Pressure; (B) Similar Samples from Steel without Seam, which show No Tendency to Split.

subjected to a pressure of 20,000 pounds, which results in flattening them out to a height of $3/16$ -inch, or to a pressure of 50,000 pounds, which flattens them out to a height of $3/32$ -inch. In all cases where there are seams in the wire, these test samples are split open by this pressure, while a perfect wire without any seams is not damaged by the treatment. At *A* in Fig. 33 is shown a sample cut from wire containing a seam and the same blank partially and fully upset; it will be noticed that, although the seam in the wire is small, it has been widened out considerably by the upsetting. At *B* in the same illustration is shown a similar set from perfect wire, comprising a blank and partially and fully upset samples, and it will be seen that the upset sample does not show any tendency to split.

In order to give some idea of the extent to which the seam at *A* was deepened by the upsetting treatment, section a-b through the blank and section c-d through the flat disk were polished, and photomicrographs of these are shown in Fig. 34. At *A* in Fig. 34 the seam in the original wire was about 0.010 inch in depth, while at *B* the depth of the seam after the blank has been upset has been increased to approximately 0.050 inch. From this it will be apparent that seams in the wire that do not appear to be of sufficient depth to give trouble may become very objectionable because of the tendency to deepen during the conversion of the stock into ball blanks. Upset disk *B* is of about the same diameter as a ball blank made from this wire by the cold-heading process, so that it has been subjected to about the same amount of stretch in upsetting that would ordinarily take place in making a ball blank by the cold-heading process. To show how trouble may develop in this way, a ball 0.375-inch in diameter is produced from a blank 0.400 inch in diameter, so that the blank is reduced 0.025-inch on the diameter, or approximately 0.013-inch on the radius. This leaves 0.050 minus 0.013, or 0.037-inch of the split extending below the surface of the finished ball, which will certainly lead to its rejection by the inspectors.

It appears that hardness of the wire does not cause splitting of the upset blank. Tests conducted with a view to establishing this fact have shown that blanks made from seamless steel

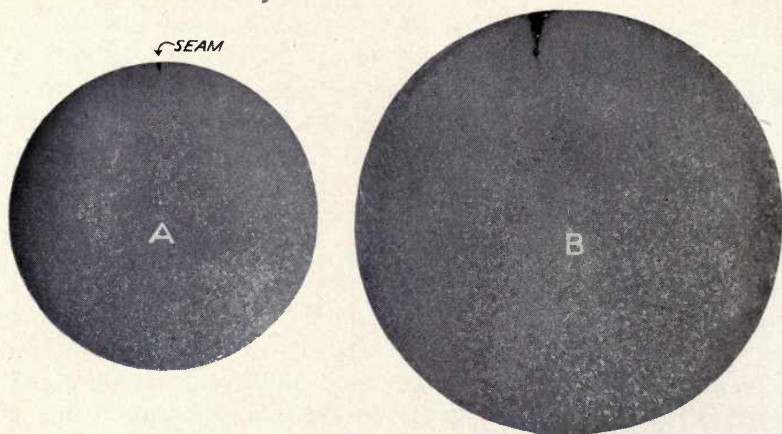


Fig. 34. Photomicrographs of Sections on Lines a-b and c-d in Fig. 33, indicating Increase in Size of Seam through stretching of Metal Surface in Upsetting.

with a high Brinell hardness number did not split under the most severe conditions of upsetting, while blanks of metal with a low Brinell hardness number, but with seams on their surfaces, were frequently split during the process of cold-heading. Specifications under which steel is purchased for the production of ball blanks in cold-heading machines call for metal with a hardness number not exceeding 170 as determined by the Brinell method, but slightly harder stock is capable of being worked with fairly satisfactory results.

HOW SEAMY STOCK ACTS IN COLD-HEADING MACHINE

IN ORDER to confirm the accuracy of the conclusions reached in regard to the action of seamy stock when worked up into ball blanks in the cold-heading machines, tests were conducted by placing coils that had bad seams in them on the cold-headers and observing the kind of ball blanks that were produced. In every case it was found that the blanks produced from such stock showed bad cracks, as shown at A in Fig. 35. In the inspection department, cracks found in finished balls were at one time commonly referred to as "fire cracks" on the assumption that they were developed during the process of heat-treatment, but they are now designated as "header cracks." In

this illustration attention is called to the fact that at the top and bottom of each ball blank there is a small projection formed by pressing the metal into the knock-out pin hole in the header dies. These have been termed "poles," and it will be noted that the poles lie on the axis of the wire. Midway between the two poles there is a band or "fin" caused by the metal being forced out between the two header dies; and this fin has been termed the "equator" of the ball.

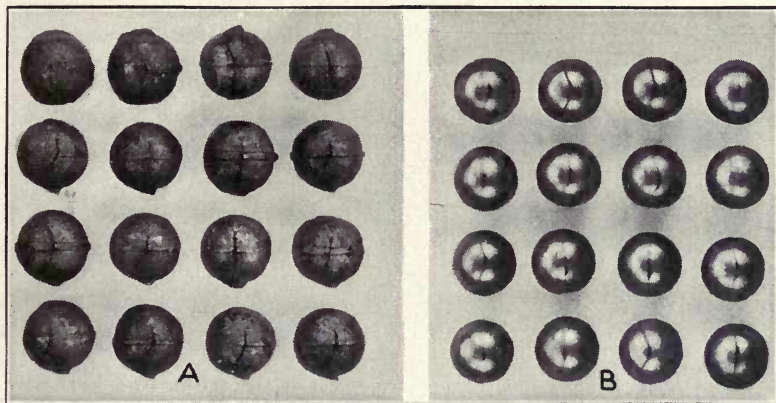


Fig. 35. (A) Cold-header Ball Blanks, showing Splits running from Pole to Pole; (B) Finished Balls produced from Blanks Split during Cold-heading Operation.

It will be noted at *A* in Fig. 35 that the header cracks run from pole to pole. At *B* in the same illustration are shown some finished balls with the same kind of cracks, and it has always been found that cracks in the finished balls have been lengthened to a considerable extent, the ends of these cracks terminating in very fine lines. This can be readily understood when we consider that a small crack or fine sharp tool mark on a piece to be hardened causes a weak spot which in many cases will result in splitting the piece during the process of heat-treatment. At *A* in Fig. 36 are shown some balls that were picked out in the inspection department because they had fire cracks; these were sent to the laboratory and fractured to reveal the grain of the metal. It will be noticed—particularly in the third ball of the third line—that at the extreme left of the fracture there is a dark spot near the surface, which is

the mark left by the original crack produced during the cold-heading operation. Then to the extreme right there is a fresh fracture which represents all the metal that the ball had to hold it together after being hardened.

Attention is called to the fact that the middle of the ball is black and oily; this is the hardening crack into which the oil and abrasive have found their way during the oil-rolling and

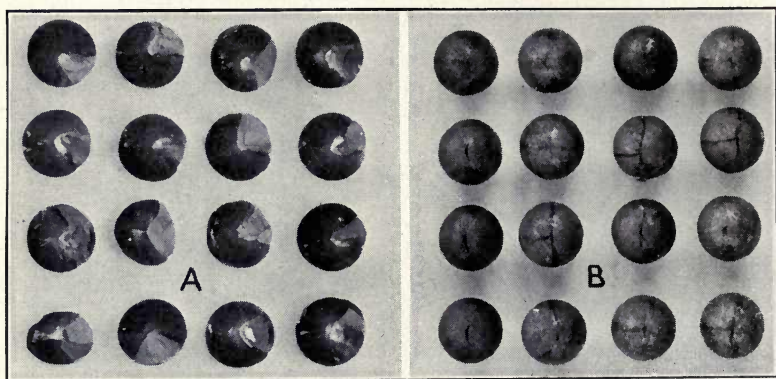


Fig. 36. (A) Fractures of Balls shown at (B) in Fig. 35, showing Original Header Crack, Fire Crack and Fracture of Uncracked Metal; (B) Etched Balls, showing Crack from Pole to Pole and Crack on Equator.

grinding operations. The crack produced in cold-heading was the cause of a further cracking of the ball during the process of heat-treatment. At B in Fig. 36 are shown some finished balls that were rejected by the inspectors because of cracks. Before being photographed these balls were etched with dilute hydrochloric acid, and it will be noticed that the cracks run from pole to pole, and in some cases there are also secondary cracks following the line of the equator. The way in which these equatorial cracks are produced can best be explained by reference to Fig. 37. At A is shown a longitudinal section of the wire which has been etched with hydrochloric acid to reveal the structure of the metal. Attention is called to the lamellar structure, which is characteristic of any steel and is no reflection upon its quality. These laminations run lengthwise of the coil. At B is shown a section of a headed ball blank made from a piece of this wire and etched with acid to bring up the

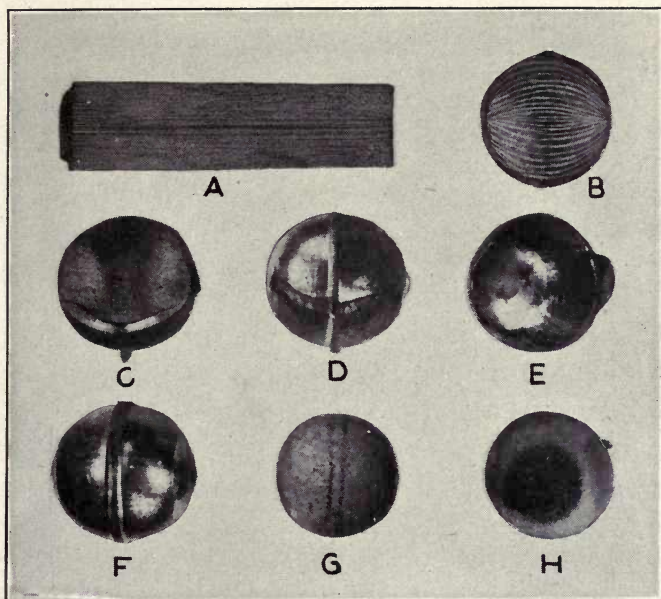


Fig. 37. (A) Section of Steel Stock, showing Lamellar Structure; (B) Cross-section of Cold-header Ball Blank, showing Distortion of Steel Structure; (C) Cross-section of Header Cracked Ball Blank; (D) Ball Blank shown in Cross-Section at (C); (E) Cold-header Ball Blank with Large Fin; (F) Perfect Cold-header Ball Blank; (G) Etched Ball, showing End Grain of Steel at Equator; (H) Etched Ball, showing End Grain of Steel at Pole.

structure of the metal. Here it will be seen that the laminations have arranged themselves in a manner similar to magnetic lines of force running from pole to pole.

At *D* and *E* are shown header-cracked ball blanks, and it will be noticed that blank *E* shows an unusually large fin on one side. Blank *D* shows the split on one side and also a portion of the split extending into the fin. Blank *F* is properly headed and shows no crack or excessively large fins. Referring to the view shown at *C*, which is a cross-section of blank *D*, it will be seen that the split extends into the fin, and it will also be noted that the crack extends below the surface of the ball, although it comes to the surface at each end at points near the poles. This is due to the fact that the split does not penetrate the ball at right angles to the surface, but runs on a slant. Instead of compressing and filling up the open space in the ball, material has been pressed outward and made a large fin; when this fin

is ground away, the crack is quite evident. At *G* and *H* are shown finished balls that have been etched with acid to show the grain at the equator and at the poles, respectively.

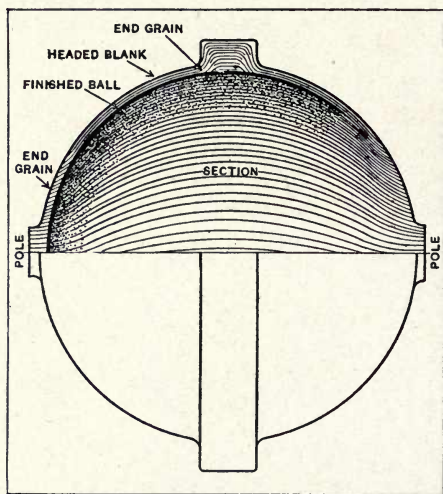


Fig. 38. Diagram illustrating Distortion of Steel Structure in Cold-header Ball Blank similar to that shown at (B) in Fig. 37.

Referring again to the sectional view of the wire shown at *A* in Fig. 37, and also to the cross-section of a ball blank made from this wire shown at *B*, it will be seen that the structure of the steel has been greatly disturbed during the process of cold-heading to produce the ball blank. In Fig. 38 is shown diagrammatically the way in which this disturbance takes place. It will be seen that the ends of the fibers come to the surface at the poles and at both sides of the equatorial fin; and when the ball is etched the steel is attacked more rapidly at these points. The peculiar marks shown at *G* and *H* in Fig. 37 are the result of this disturbance of structure. The conclusion has been reached that when a ball with so-called "header cracks" is etched with acid and shows two end poles and two equatorial marks with a wide crack running from pole to pole or possibly a secondary crack running between the two equators, this crack is a header crack which is caused by a seam or lap in the steel from which the ball was made. The internal stress due to the structural distortion illustrated in Fig. 38 is completely normalized by the

annealing treatment to which all Hoover balls are subjected.

A number of these headed balls with header cracks were heated in an electric furnace in the laboratory and quenched in water at 1500 degrees F.; every ball was further cracked by this treatment, and several of them fell in half or were easily broken by a light hammer blow. Another lot of headed balls with no header cracks was heated in the electric furnace and quenched in water at 1600 degrees F., and not a ball was cracked in hardening. Balls quenched in water at 1500 degrees F. that broke during the process of heat-treatment are shown at *A* in Fig. 39, while the balls quenched in water at 1600 degrees F., without damage are shown at *B* in the same illustration. At this excessive temperature the grain of the metal was coarsened, but no hardening cracks were produced and it required considerable force to break the balls. Several finished balls were next selected in the inspection department that showed very slight header cracks. These balls were hardened at 1500 degrees F. and cracked in the process of hardening exactly as before. The characteristic black mark left by the original header crack is shown at one side of the balls at *C* in Fig. 39. Another lot of finished balls showing no header cracks was hardened at 1600 degrees F. and none of the balls was cracked, views of the fractured surfaces of these balls being shown at *D* in Fig. 39. This confirmed the accuracy of previous tests, and from these data the following conclusions were drawn: (1) The header crack forms a weak spot, so that when the ball is hardened, even at the proper temperature,

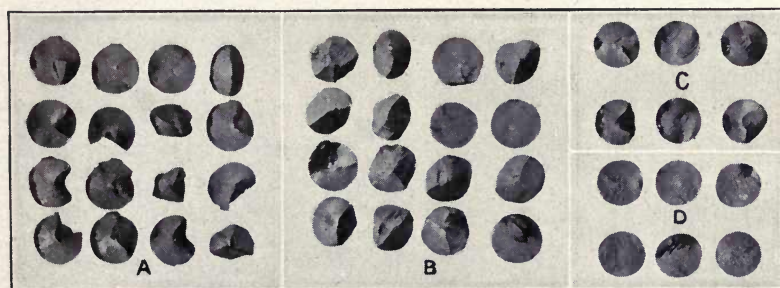


Fig. 39. (A) Fractures of Header Cracked Balls that Split when re-heat-treated in Laboratory at 1500 Degrees F.; (B) Fractures of Perfect Balls that did not Split when re-heat-treated at 1600 Degrees F.; (C) Fractures of Balls with Slight Cracks which broke when re-heat-treated at 1500 Degrees F.; (D) Fractures of Perfect Balls that did not break when re-heat-treated at 1600 Degrees F.

what the inspectors call a "fire crack" is likely to be produced. (2) A ball with no header cracks can be hardened at an excessively high temperature without producing a fire crack.

Another hardening test was made with four samples of wire, two pieces of which showed seams, and two pieces that did not. The seamy pieces of wire were quenched at a temperature of about 1500 degrees F. in water and hardening cracks developed along the seams. The two pieces without seams were quenched in water at a temperature of 1600 degrees F. and no cracks developed. All these tests show that with small blanks without any header cracks, it is practically impossible to produce fire cracks in the automatic hardening furnaces; when cracks are produced they are started in cold-heading and not through the process of heat-treatment. The shape of the ball is in its favor, as it insures uniform quenching and a minimum of internal strain. Application of too high a temperature would tend to increase the size of the grain in the steel and make it brittle and unfit for use, but it would not produce hardening cracks.

EFFECT OF HARDNESS OF WIRE

WHEN the wire used in making ball blanks on cold-headers is too hard, there is a tendency for it to break off instead of shearing as it should. When trouble of this sort is encountered, it is likely to be accentuated by the fact that the blank is often carried to the heading die in a sidewise position, which results in the development of abnormal pressure in the die. Working hard stock of this kind results in breaking the cut-off knife or the dies on the cold-heading machine. This condition of excessive hardness does not usually exist for the entire length of the coil; wire may shear off and head nicely for some time, when suddenly a hard spot will be reached and then the dies or the cut-off knife is likely to suffer. After this hard spot has been passed, the wire may be all right for another period of considerable duration. With the view of showing the relative condition of hard and soft spots in the wire, slugs of metal were selected at a point where trouble was encountered from this cause, and again at a point where the operation of the cold-header was entirely satisfactory. These were tested

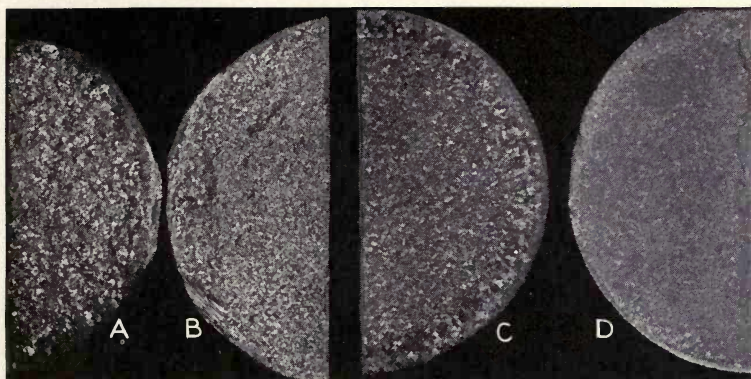


Fig. 40. (A) Fracture of Hard Metal Slug; (B) Fracture of Normal Metal Slug; (C) Etched Surface of Hard Steel magnified 5.25 Diameters—Attention is called to Decarbonization at Circumference; (D) Etched Surface of Normal Steel with No Decarbonization at Circumference.

by the Brinell method and it was found that the hard slugs had a Brinell hardness number of 215, while the soft slugs only showed a Brinell hardness number of 190. The latter is really higher than it should be, as 170 is specified for steel to be used in cold-heading machines.

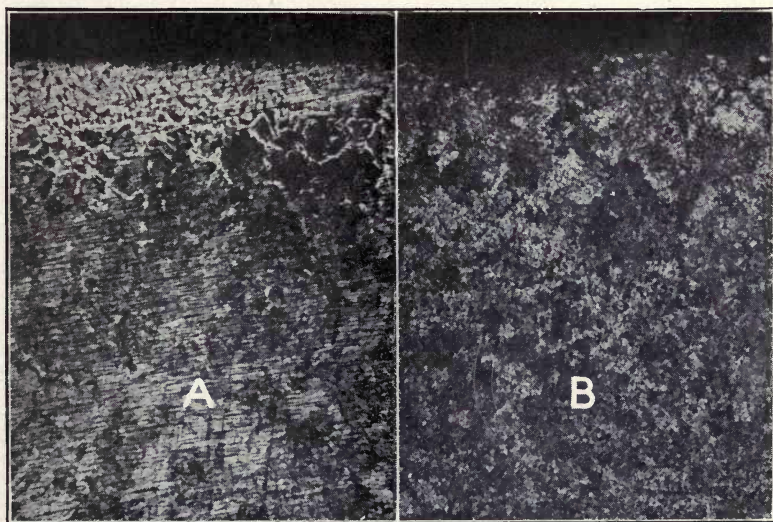


Fig. 41. (A) Decarbonized Surface shown at (C) in Fig. 40 magnified to Sixty-two Diameters; (B) Same Magnification as at (A), showing Condition of Practically No Decarbonization.

At *A* in Fig. 40 is shown the fresh fracture of a slug of hard metal and attention is called to the coarse grain as compared with the finer grain of the normal steel shown at *B*. The hard specimen was very brittle and easy to break, while the normal steel was tough and capable of bending considerably before being broken. Specimens of these two steels were next polished and etched, with the result shown at *C* and *D*, respectively. These are transverse sections cut through the wire, and attention is called to the coarse grain of the steel shown at *C*; the ring at the surface is a band of decarbonized steel apparently produced by the application of too high an annealing temperature. The normal steel shown at *D* has a fine grain and there is no indication of decarbonization.

At *A* in Fig. 41 is shown the decarbonized band of steel surrounding section *C* in Fig. 40, which is magnified to 62 diameters, instead of 5.25 diameters, as in the case of the previous illustration. It will be noted that the extreme edge of this photomicrograph is somewhat indistinct, owing to the slightly rounded edge formed while polishing the specimen. The decarbonized surface of this stock would not be entirely removed in the process of grinding, and would result in the production of either soft balls or balls with soft spots. At *B*, Fig. 41, we have the condition where there is practically no loss of carbon at the surface. At *A* and *B* in Fig. 42 is seen a decided contrast between the

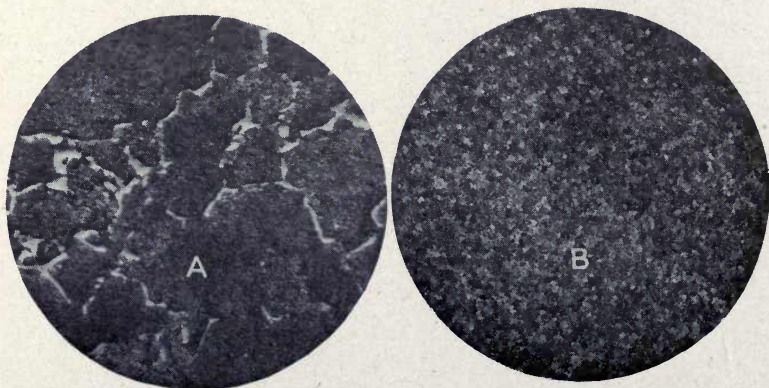


Fig. 42. (A) Pronounced Pearlitic Structure with large cells and Boundaries of excess Cementite, indicating Application of too High an Annealing Temperature; (B) Fine-grained Structure, showing Condition obtained with Proper Annealing Temperature. Both Samples magnified to 225 Diameters.

structure of the slug of hard metal and that taken from the normal wire. At *A* there is a pronounced pearlitic structure with large cells and distinct boundaries of excess cementite, which also indicates the application of too high an annealing temperature. At *B* the structure is fine grained, which is the condition produced by employing the proper annealing temperature. Where lack of uniformity is discovered in the hardness of the wire, it is probably due to application of too high an annealing temperature.

CAUSE OF SOFT SPOTS ON BALLS

SOME valuable discoveries have been made in the laboratory as a result of work that was started with some other object in view. For instance, an investigation that was started with the view of determining the effect of slight seams found in a certain shipment of steel at the time of the preliminary tests. These seams were not considered serious enough to justify rejection of the steel, but after the first lot of blanks had been finish dry ground, tests were made. This was done by etching a number of balls in dilute hydrochloric acid, to see if the seams had been removed in grinding. The balls were immersed in the solution, and after being etched for fifteen or twenty minutes they were removed, and cleaned.

When treated in this way, the balls are usually a light gray color over their entire surface, but the particular lot of balls referred to could not be uniformly etched. At first it was thought that a film of grease or some other foreign matter was interfering with the action of the acid, but a second trial resulted in the same mottled appearance of the etched balls. Part of the surface was light gray, while other parts were dark gray and almost black. Balls with these spots are shown in Fig. 43 and no matter how often they were re-etched, the same spots always appeared and they were of the same outline as those developed by the previous etching. Some of the unetched samples were examined, and it was found that a considerable quantity of black scale was left on the balls, *i. e.*, the forging had not been cleaned up properly after the finish dry-grinding. At this stage the ball

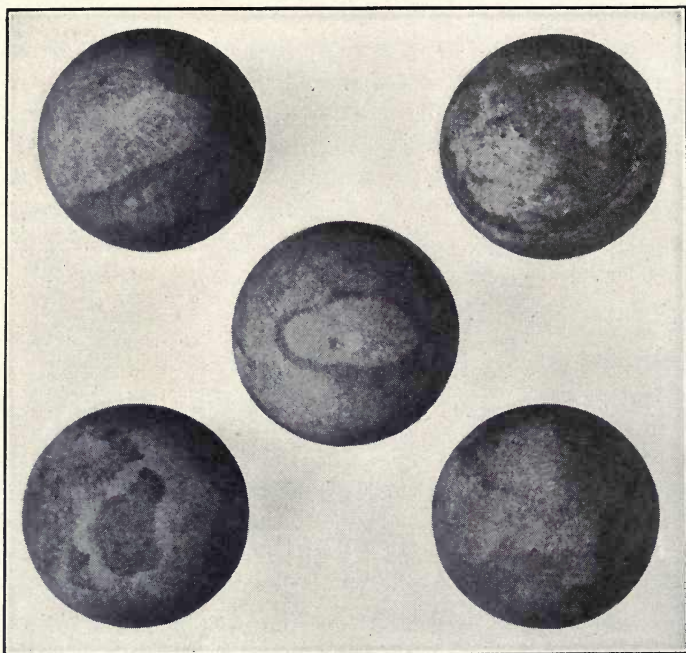


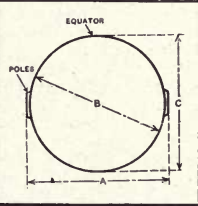
Fig. 43. Finish Dry-ground Balls after being etched with Hydrochloric Acid, showing Mottled Appearance due to Soft Spots produced by Decarbonization of Steel.

consistently measured 1.135 inch, *i. e.*, within 0.010 inch of the finished size— $1\frac{1}{8}$ inch.

Thus far results seemed to indicate that the forging blanks were under size, so five samples were selected at random and measured. The measurements of these five blanks are given in Table 4, reference to which will show that dimensions *A* across the poles and dimension *B* near the poles were of ample size; and the surfaces at or close to the poles were also smooth and well filled out. However, these conditions did not exist around the equator, where it will be seen that dimension *C* was scant in many balls, and additional trouble was caused by the fact that the surface was very rough and covered with "hills" and "valleys." In making these equatorial measurements with a micrometer, the distance is taken across the tops of the "hills," while the dimensions in the "valleys" will obviously be considerably less. It is doubtful, therefore, whether three out of five of

these samples would clean up in the rough dry-grinding. A re-examination of the etched dry-ground balls showed that the peculiar black spots did not appear at the poles as frequently as they did at the equator; and when a new file was applied to the black spots shown in Fig. 43, it was found that they were dead soft, while the light gray spots were very hard. The scleroscope hardness of ten of these balls was taken and averaged as follows: black spots, 48; gray spots, 70.

Table IV. Measurements of Balls across Poles, near Poles and at Equator.

Sample	A	B	C				
1	1.169	1.167	1.166	1.161	1.160	1.166	
2	1.166	1.165	1.161	1.157	1.163	1.162	
3	1.168	1.155	1.151	1.145	1.145	1.150	
4	1.169	1.175	1.175	1.172	1.170	1.159	
5	1.170	1.168	1.152	1.170	1.158	1.167	

The reason for these spots will be understood from the photomicrographs presented at *A* and *B* in Fig. 44, which are taken from polished surfaces at the extreme outer surface of the black and white spots on the balls. These surfaces were prepared and photographed in exactly the same way; instead of polishing a flat on the ball, the spherical surface was polished, because a flat surface having any width whatever would also be at a considerable depth below the surface of the ball, and would not reveal conditions that it was desired to investigate. Difficulty was experienced in polishing this spherical surface, and so the photographs reproduced in Fig. 44 show polish marks rather too distinctly, but these have no bearing upon the accuracy of the results obtained in the investigation. At *A* is shown a large percentage of free ferrite, indicating a hypo-eutectoid structure of about 0.30 to 0.40 per cent carbon; in other words, the metal is similar to a mild steel. On the other hand, the condition revealed at *B* is practically a pure eutectoid structure of pearlite, this steel having from 0.85 to 0.90 per cent carbon. Specifications under which the steel is purchased call for from 0.95 to 1.05 per cent of carbon, so that in this regard it fulfills requirements.

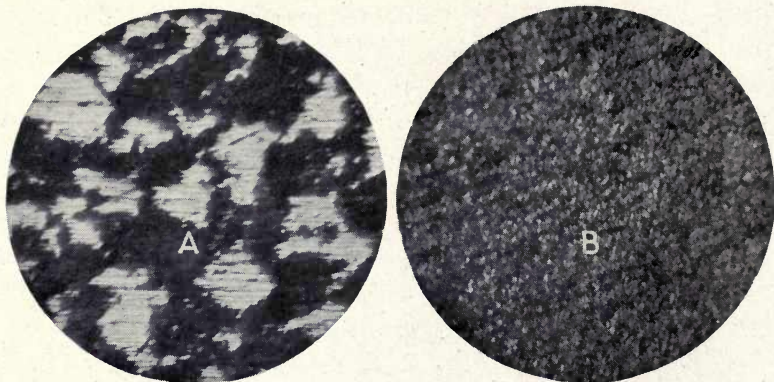


Fig. 44. (A) Photomicrograph of Black Soft Spots on Balls shown in Fig. 43, showing Large Percentage of Free Ferrite or Hypo-eutectoid Structure; (B) Photomicrograph of Hard White Spots on Balls shown in Fig. 43, indicating the Desired Eutectoid Structure.

A further test was conducted by preparing flat surfaces of considerable depth on the balls and examining these under the microscope; and in both cases it was found that photomicrographs obtained in this way indicated metal containing its full percentage of carbon. Hardness tests show that the metal directly under the decarbonized spot is soft and indicate not only that the decarbonized surface fails to harden, but that it also forms a sort of insulator and retards the proper hardening of the eutectoid steel beneath it. Therefore, the decarbonization plus its effects means a soft area of decided depth, so deep, in fact, that when the ball is finished the soft spot still appears. Having reached this conclusion, specimens of the raw material were prepared by cutting sections transversely from the bar, and these were prepared and photographed Fig. 45 illustrating the conditions that were revealed in this way. It will be noted that the steel shown at *A* is decarbonized to a depth of 0.010 inch—0.020 inch on the diameter of the ball—while in the sample shown at *B* there is no decarbonization. It was this steel with the decarbonized surface that produced balls showing soft spots in the tests.

Fifty of these balls showing soft spots were taken to the laboratory, where they were again heat-treated, and the result was that the balls came out hard. It was not considered, however, that this indicated defective heat-treatment in the process

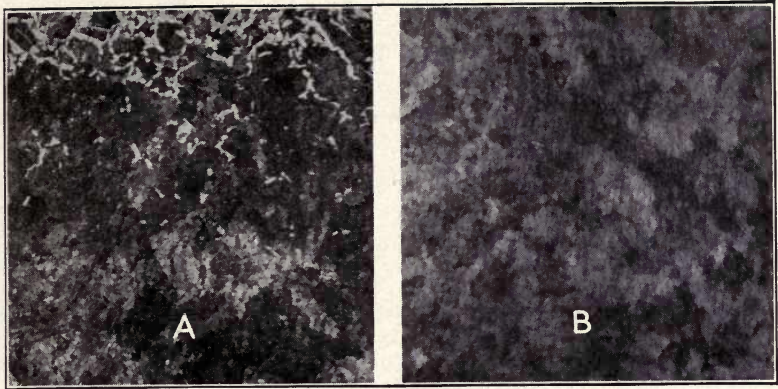


Fig. 45. (A) Photomicrograph of Transverse Section of Decarbonized Edge of Steel—Magnification, 125 Diameters; (B) Photomicrograph of Transverse Section of Steel showing No Decarbonization—Magnification, 125 Diameters.

of manufacture, because it might have happened that the operation of finish dry-grinding removed enough metal from the surface so that the balls would harden properly, although they were prevented from doing so at the time of the original treatment by the decarbonized steel that covered the surface of the balls. Because of the oval shape of the forgings, the depth of decarbonization varies at different spots on the rough-ground surface of the balls; for example, at the poles there is little or no decarbonization, while around the equator the decarbonization is quite deep. When a ball is reduced to the finished size, the following conditions will be found: (1) decarbonized areas where the original decarbonization on the rough ball was deep; (2) soft areas where the original decarbonization on the rough ball was shallow; (3) hard areas where there was little or no decarbonization on the rough ball. In cases (2) and (3) the steel has its full percentage of carbon, and when the balls are rehardened some of the soft spots disappear, while the spots devoid of carbon still remain soft. It would be possible to reduce these balls to a smaller size and reclaim them by rehardening, but this subsequent heat-treatment has a tendency to roughen their surface slightly, which necessitates subsequent grinding operations that would probably reduce the diameter from 0.015 to 0.020 inch, so that allowance must be made for this reduction in size.

To overcome trouble from the use of stock that is decarbonized at the surface, special forging dies were made which produce oversize ball blanks, so that the diameter at the equator measures from 0.060 to 0.080 inch more than that of the standard finished balls. The same stock forged in a regular die would make a blank 0.025 inch to 0.035 inch larger than the finished size. In the present case it is found that these would not clean up, but left soft and decarbonized spots on the surface of the finished ball. For this reason, the special forging dies were produced. This practice was adopted because, owing to the slow deliveries made by the steel mills, it was desired not to reject any steel of this size that could possibly be used.

DEVELOPMENT OF A DEVICE FOR SEPARATING HARD AND SOFT BALLS

OWING to shipment to the factory of a large quantity of low carbon steel through an error made at the steel mills, and which escaped the rigid sampling to which every car of steel received at the Hoover plant is subject, about seven tons of this material was converted into ball blanks before it was attempted to harden them. This was due to the fact that a large supply of blanks of the same sizes had accumulated, and these were naturally sent through the heat-treating department ahead of blanks made from this shipment of steel. When the blanks had been heat-treated, they were tested in order to determine the nature of the results obtained, and while a number of balls broke with a fine-grained fracture and showed a hardness that was all that could be desired, almost 10 per cent of the balls were found to be dead soft. When these balls were subjected to pressure they flattened out instead of breaking in the usual way. A peculiar mottled effect was noted on the balls found to be file hard, while the soft balls were a dull black color; but this difference in appearance was not sufficiently marked to enable the balls to be separated, and even had this been possible, the length of time required to eliminate defective balls by this method would have been prohibitive.

With a view to overcoming this difficulty, a device was developed which is shown in diagrammatic form in Fig. 46. Its principle of operation is based on the fact that when balls are

dropped on a hardened steel anvil there is considerable difference in the height of the rebound of hard and soft balls. The balls to be tested roll down an incline plane and drop upon a hardened steel block, from which they rebound; the hard balls rise high enough to pass over a "hurdle" into a box, while the soft balls do not reach this height and are deposited in a second box. To test the efficiency of this device, 119 balls taken from one of the tote pans in the shop were run through the drop test; 79 dropped into the "hard bin" and 40 into the "soft bin." These balls were once more thoroughly mixed and again run through the apparatus with the same result as in the previous case. Additional trials confirmed the accuracy of the apparatus. This method of separation proved so satisfactory that a regular equipment has been built for use in the dry-grinding room, where it is used for separating hard and soft balls.

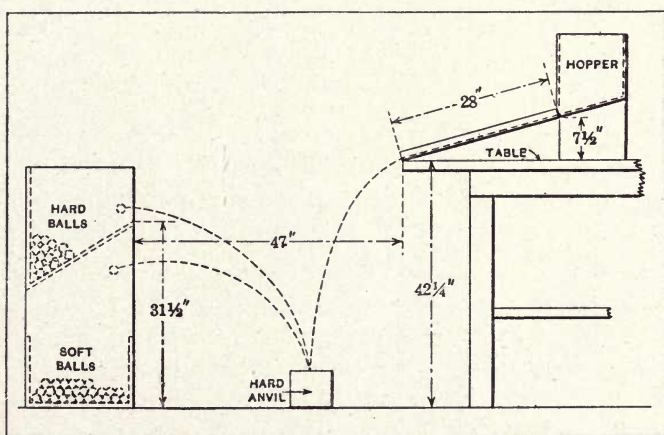


Fig. 46. Diagram illustrating Principle of Apparatus developed for Automatic Separation of $\frac{3}{4}$ -inch Hard and Soft Balls.

CONCLUSION

MANY of the cases of trouble to which reference has been made are of rare occurrence, but it is obvious that they exert a powerful influence on the quality of the product turned out in the factory. Also, the conditions brought to light by these investigations are exceptionally interesting. It was on

this account that they were selected for discussion in the present treatise, in connection with the regular work of the laboratory, and not because they really belong to a description of routine work of testing the raw material and product of a factory engaged in the manufacture of steel balls.

CRUSHING AND DEFORMATION TESTS

THE old method of determining the crushing load of a ball was to test a single ball between two hardened steel plates. It is obvious that if the plates were not of uniform hardness the crushing loads would also lack uniformity, because the plates would be indented during the test and the softer plate, being indented the greater, would present more supporting area to the ball, and thereby increase its resistance to crushing. Inability to produce plates of absolute uniformity puts this method out of the question as a standard test.

The Hoover Steel Ball Co. has developed the Three-Ball test as a standard. Three balls super-imposed, as shown in the illustration, are subjected to a gradually increasing pressure until rupture occurs, and the amount of pressure is recorded at this point.

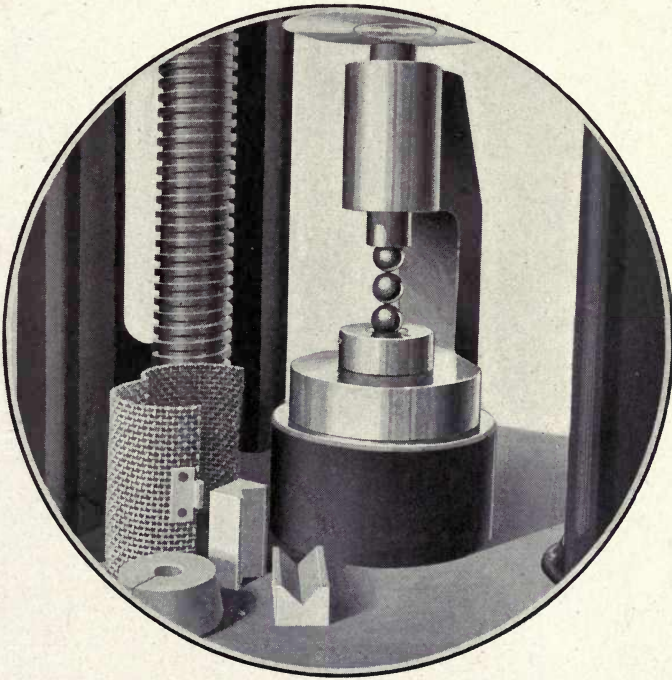
We wish to emphasize that testing by the Three-Ball method will yield results somewhat lower than by the plate test by reason of the fact that the contact points are very minute and therefore the pressure per unit of area is tremendous.

The plate test is very often used by some ball manufacturers to deceive the buyer by making him believe he is getting a better ball by reason of the high crushing load.

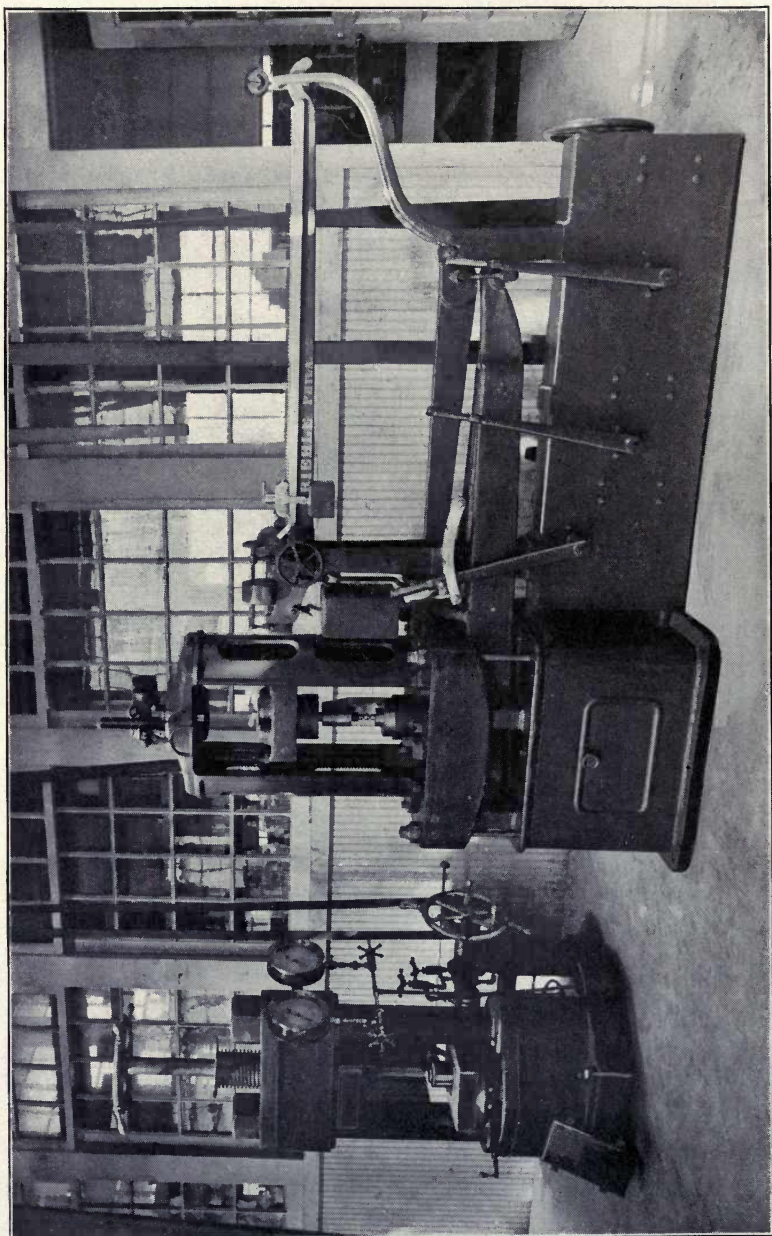
Believing that a table of crushing loads would be of very little value to our customers, as a guide to determine the safe working load of the ball, and that such a table might be misleading, we refrain from publishing same.

It is evident that the safe working load that a ball will carry depends not only upon the quality of the ball, but also upon the type of bearing in which it is to run, the shape, material and finish of the ball race, etc.

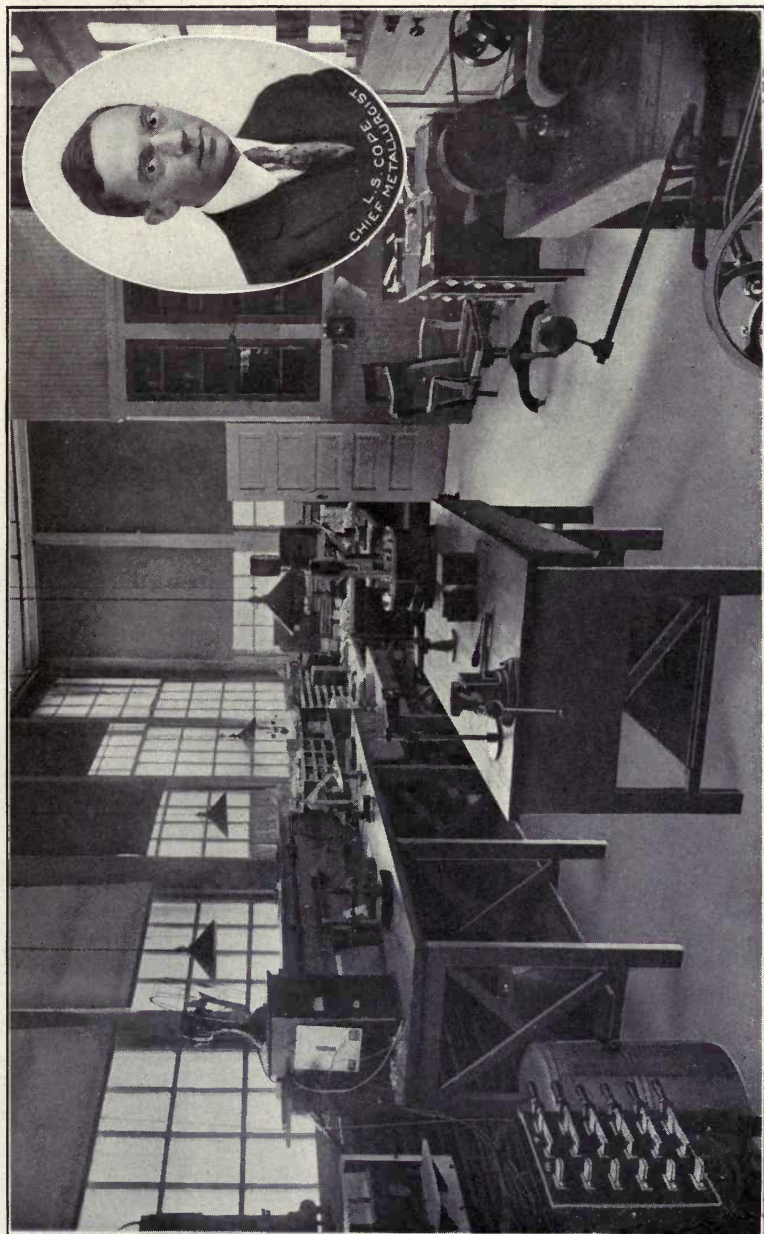
We stand ready at all times, however, to give our customers information as to crushing strength and elastic strength, and to give our opinion as to the most suitable size and type of ball for any particular work, after we have received full particulars of the bearing and the nature of the work for which it is required, load, speed, etc.



Ball Crushing Apparatus

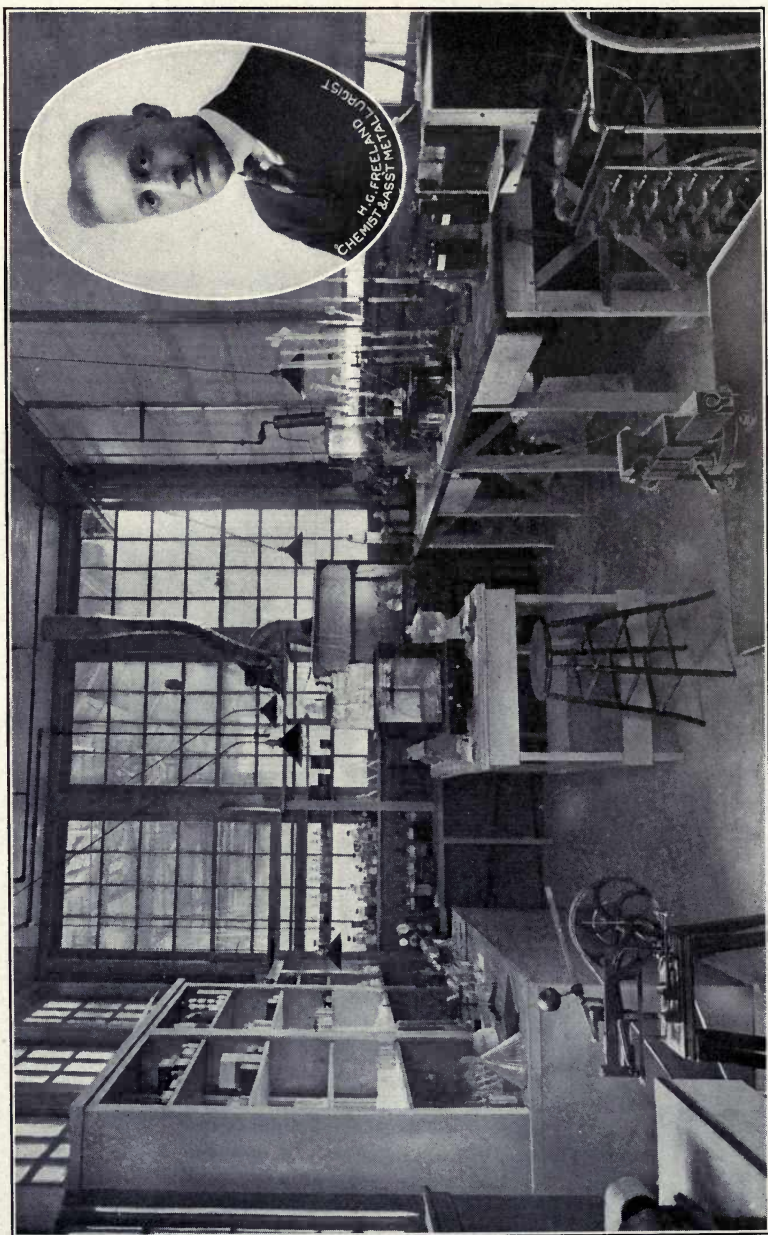


THE TESTING MACHINES—in which every batch of Hoover Balls is subjected to compression and deformation tests. All of our tests are made on three balls superimposed.



PHYSICAL LABORATORY—Extensive routine and research work is being constantly carried on to make the Hoover Ball as perfect as possible.





CHEMICAL LABORATORY—Rigid examination and supervision of the materials which go to make up Hoover Balls insures uniformity of the quality of the finished Ball.



Fracture of a hard surface tough center ball. Note the flattening and cone of rupture at the points of contact, formed when the balls were crushed.

HOOVER STEEL BALLS HAVE A HARD SURFACE AND A TOUGH CENTRE

CO-OPERATION with our customers and extensive service tests of our balls have developed a method of heat treatment which while simple in its theory is difficult of practical control, and this control is only made possible by automatic hardening machines which eliminate the personal element.

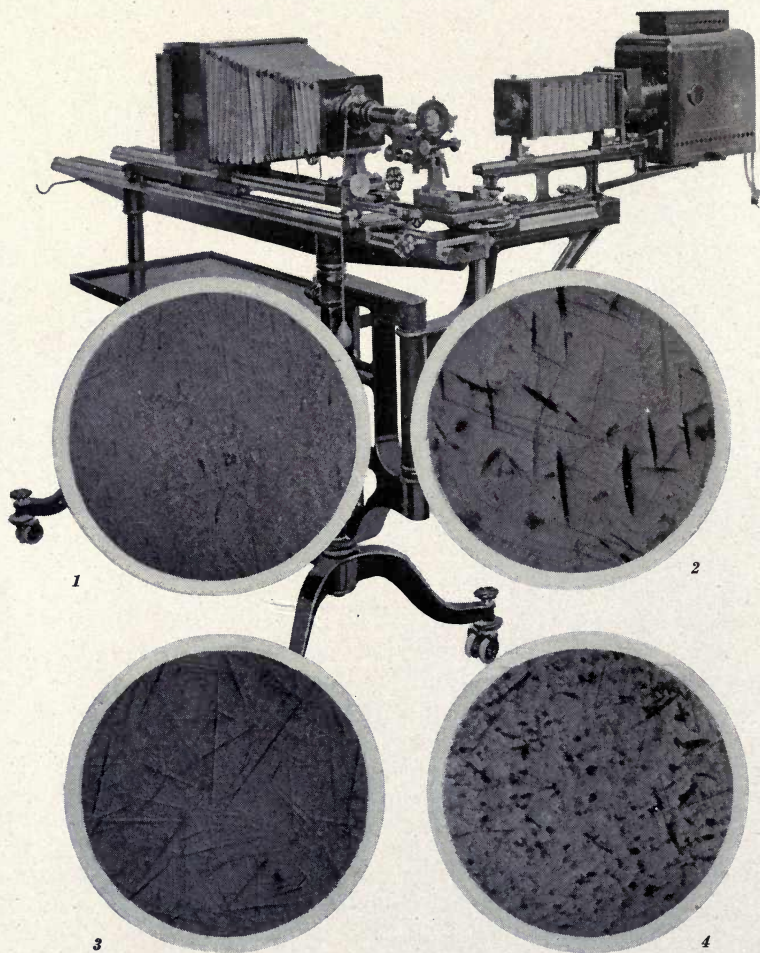
It is not a difficult matter to harden a ball clear through to the centre, as it is merely a question of quenching at a temperature sufficiently high to harden the interior, but this method is without due regard to the exterior. Hardening a ball under these conditions produces an over-heated exterior which is necessarily brittle, and strength cannot be restored by tempering.

Hoover balls are heat-treated to produce a sufficiently hard exterior and a tough semi-hard interior, producing the qualities most needed in ball bearings. The surface is sufficiently hard to withstand wear, without being so brittle as to flake or peel. The interior is sufficiently tough and elastic to stand the strain of heavy loads.

This type of ball must not be confused with a low grade steel ball "case hardened" on the surface and with a soft core.

When we speak of hard surface and tough centre we refer to a high grade alloy steel in which there is a gradual merging of hardness at the surface to semi-hardness at the core, without a distinct line of demarkation as in the "case hardened" ball.

The above photograph shows the fracture of a hard surface, tough centre ball, of which the Hoover Steel Ball Co. is the exponent.



SMOOTH AND MIRROR-LIKE surface finish must be maintained in every ball leaving our plant and to this end extensive microscopic examinations are regularly made. The constancy and effect of the many abrasive materials used are kept under rigid control.

Microphotographs 1, 2, 3 and 4 show the highly magnified surfaces of several makes of balls for comparison.

No. 1 shows the Hoover standard.

At the top of this page is shown the apparatus on which microscopic examinations and photographs are made.

CHEMICAL LABORATORY

WE HAVE an up-to-date Chemical Laboratory which co-operates with the Metallurgical Department in the control of the raw material which is used in the production of the Hoover Steel Balls, as well as the solution of the different problems which are constantly arising in a plant that is aiming to produce a product as near perfect as scientific methods and human efficiency can make it.

Drillings, and in some cases millings, are taken from the samples which are brought to the Metallurgical Department from each shipment of steel which is received at the plant, whether for the production of balls or to be used for the production of machine parts that may be required in the plant. These drillings, or millings, as the case may be, are analyzed in the Laboratory. The percentage of carbon, manganese, phosphorus, sulphur and chromium is determined in all steel used for the production of balls. In the case of Header Die Steel, which is used to make the dies that forge the balls, the percentage of carbon is determined on each bar, and if it should be an alloy steel other elements are determined, and a complete analysis is made on one sample taken from the shipment.

Samples are also taken from each shipment of Brass and Bronze Wire or Rod, which is received at the plant, and from which are made our Brass and Bronze Balls. These are analyzed to determine the quantities of tin, lead, copper, iron, zinc, and also any elements that might have an injurious effect on the service rendered by the finished balls. As the composition in a great measure controls the hardness, resistance to abrasion, resistance to corrosion, and therefore the life of the finished balls, it can be seen how very important it is that a careful analysis should be made of all raw material from which these balls are produced.

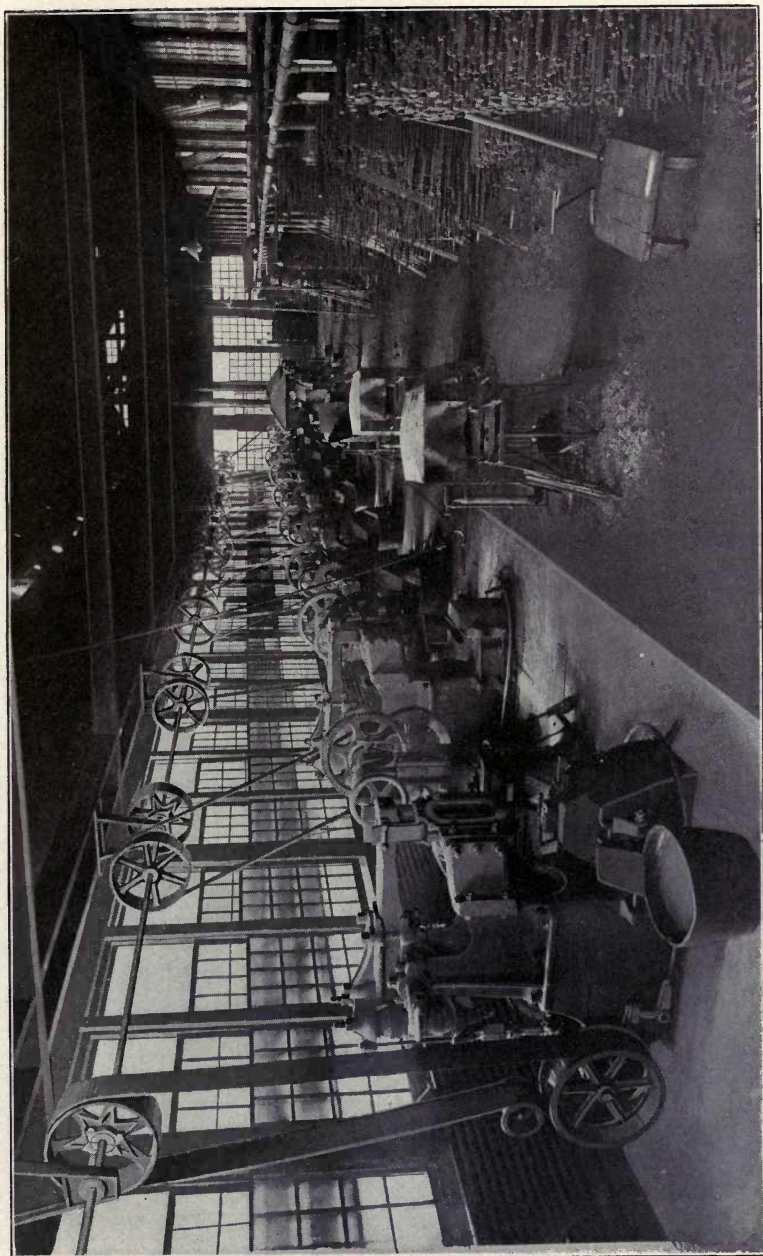
A great many oils and greases are used in the plant for various purposes, and these must be all carefully tested and graded. For instance, the finished balls are packed in a mixture of an oil and a grease and it is very important that these should be absolutely free from any element such as acids, sulphides or water, as any of these would etch and oxidize the surface of the

balls in a short time so that they would be rendered useless for our customers. The same thing applies to the paper used in lining the boxes in which the balls are packed for shipment. The leather used to put the final polish on the balls must also be free from acid and moisture, or they would be rejected by the Inspection Department on account of rust spots. A surface so highly finished is very sensitive and must be carefully protected not only during production but in the packing, and this is the reason the surface of the balls is so carefully covered with oil to prevent even the atmospheric moisture affecting them.

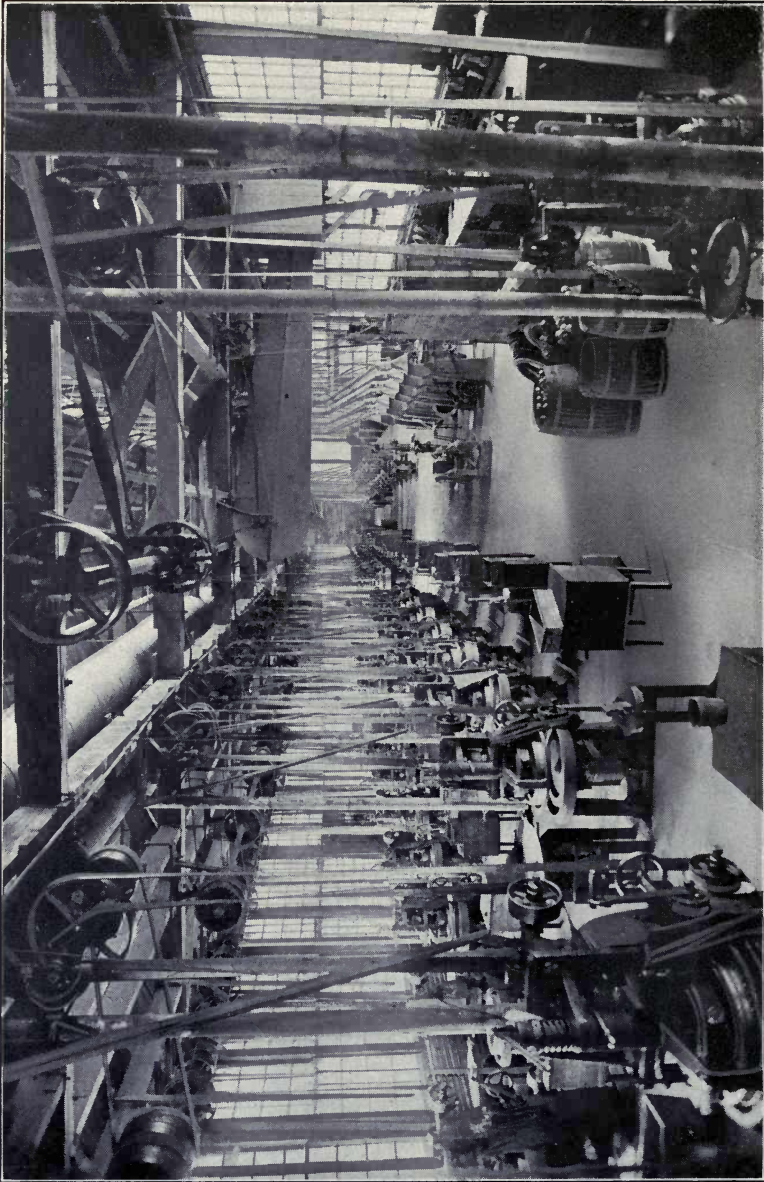
Fuels in the form of coal, oil and gas are also graded and combustion problems investigated in this department. The effect on the finished product of the different modes of handling the balls during production must be considered, and even the humidity of the room in which they are inspected has to be reckoned with. It can, therefore, be seen that besides the routine control of raw material, etc., a number of interesting questions arise from time to time which the Chemical Laboratory must assist in solving.



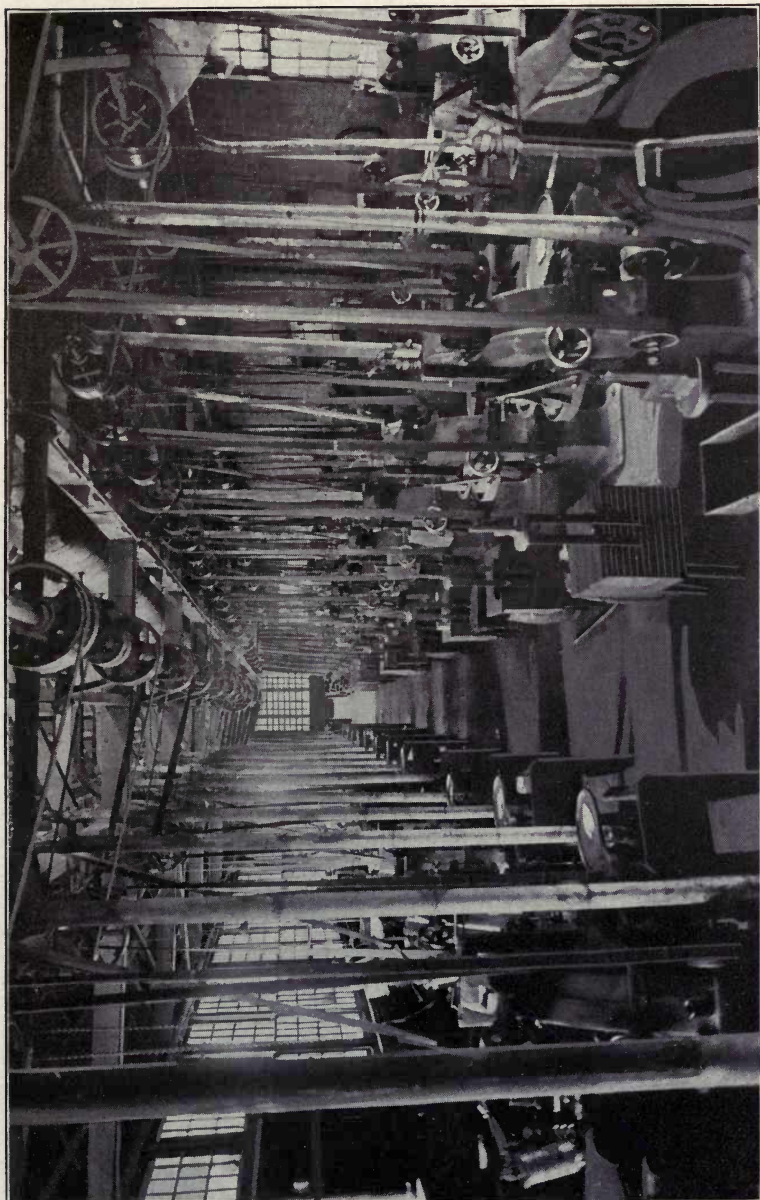
HEADER DEPARTMENT—A battery of Manville Cold-headers operates continuously, night and day, pressing out blanks for Balls up to and including $5\frac{7}{8}$ " diameter.
 Note the piles of Steel Wire and Coil Stock on the left of the photograph. Some of these machines operate at a speed of 120 strokes per minute, and a Ball is formed every stroke. The larger machines operate at a slower rate of speed. Brass and Bronze Balls are also formed on these Cold-headers.



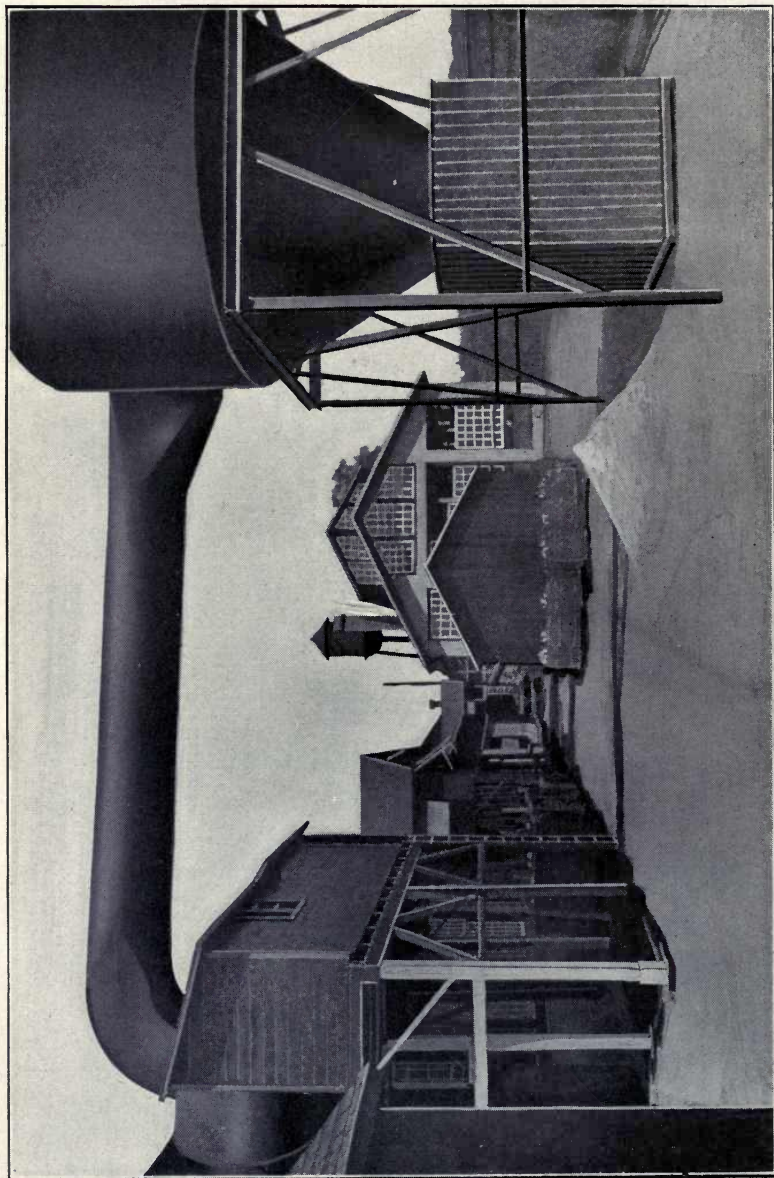
HAMMER SHOP—Balls larger than 5/8" diameter are forged in strings, from the hot rolled Bar Stock. Bradley hammers are used and each hammer is accompanied by a press and a forge. Part of the stock bins is shown at the right.



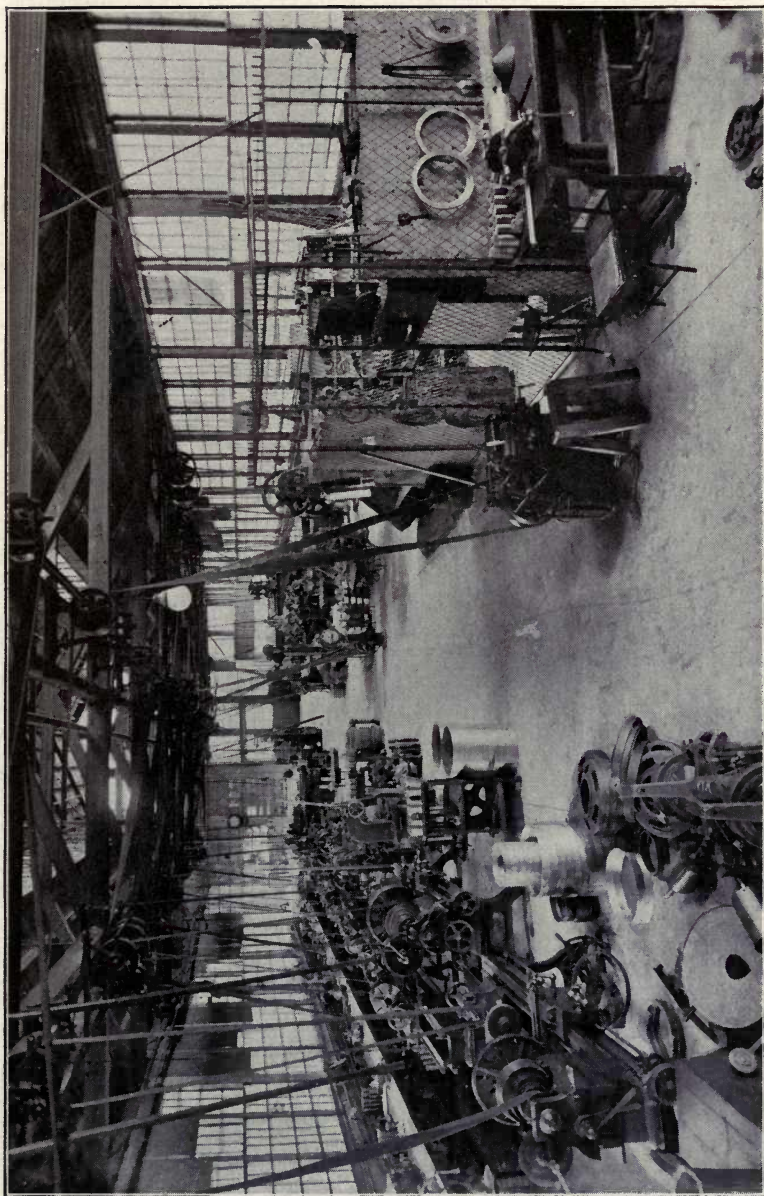
THE DRY-GRINDING DEPARTMENT—This view is looking south from the center of room. These are special machines which have been adopted after years of experimenting. All balls from $1/8$ " to 2" in diameter are ground on these machines. Our process is the same for all sizes.



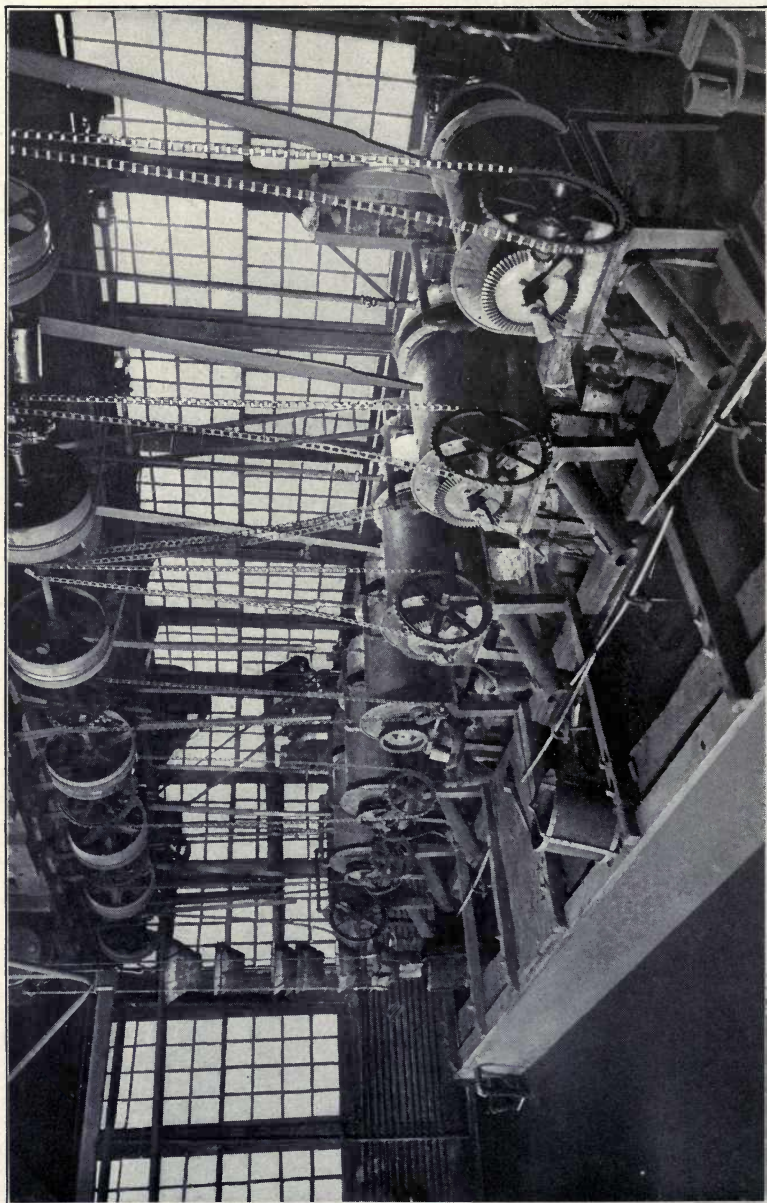
THE DRY-GRINDING DEPARTMENT—This is a view of the same room as shown on the opposite page, but looking north from the centre of the room.



This photograph shows the means of purifying air in the Dry-grinding Department. With several hundred of these grinders working dry the air would become filled with a cloud of grinding dust dangerous to breathe. We have overcome this completely by equipping each individual machine with a combination wheel-guard and dust collector. The dust is carried outside the building by means of a powerful blower to the large dust collector shown in the view above.



THE MACHINE SHOP—which keeps in repair the many machines which work continuously night and day making Hoover Balls. Our balls are made on special machines which have been designed and built in our plant. A department of the machine shop is kept busy continuously on the manufacture and upkeep of dies which we use in very large quantities.

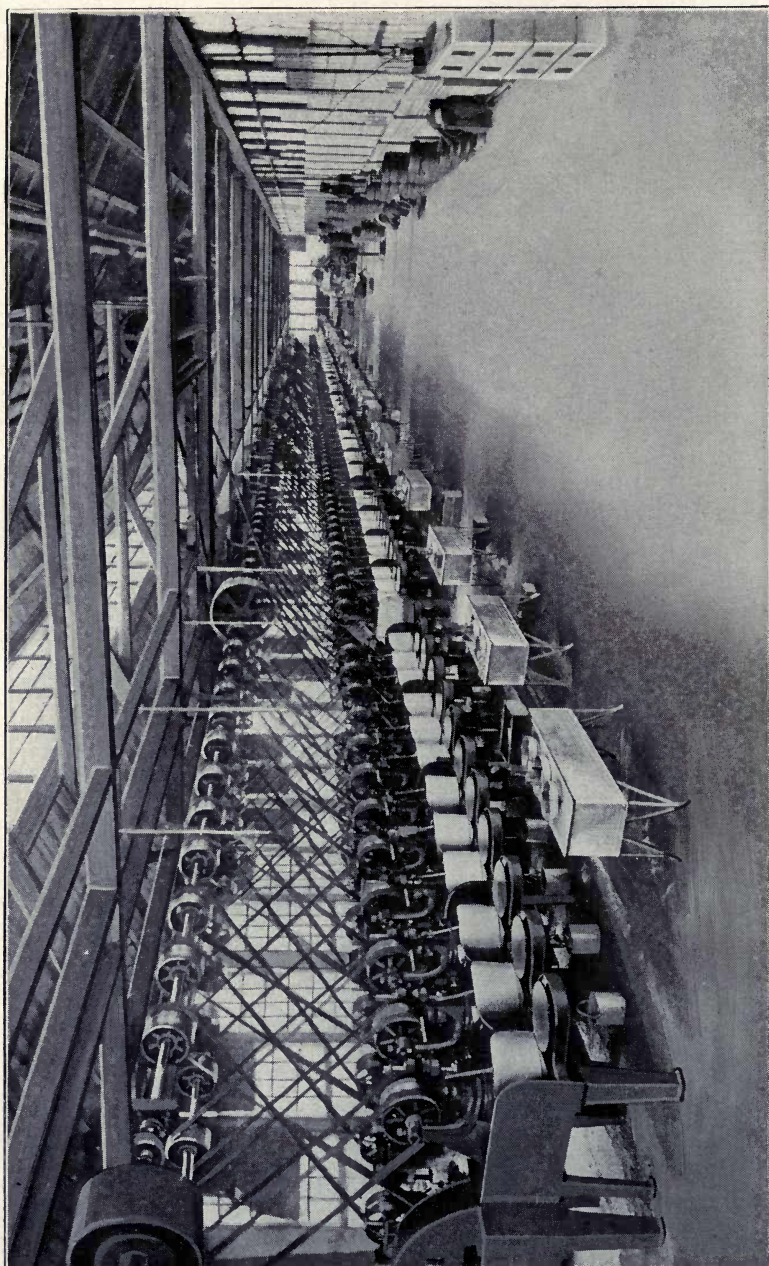


A ROW OF AUTOMATIC HEATING MACHINES—is used to harden balls up to and including 1" in diameter. By our special heat treatment the balls are given the hard surface and tough center so essential to maximum endurance in ball bearings. The balls are quenched by dropping by a circuitous route to the bottom of tanks fourteen feet deep. The quenching medium is automatically kept at a constant temperature and the furnaces are all under heat control, insuring uniformity.



ANOTHER VIEW OF THE HARDENING ROOM—Showing a battery of "Frankfort" Furnaces used in heat-treating the larger sizes of Balls. The temperature of the furnaces and quenching medium are under automatic control. After Balls are hardened they are tempered slightly to relieve all strains, but at the same time retaining the hard surface and tough center.

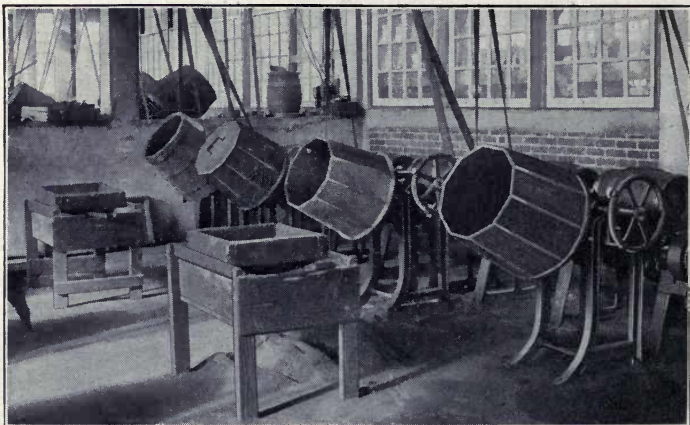
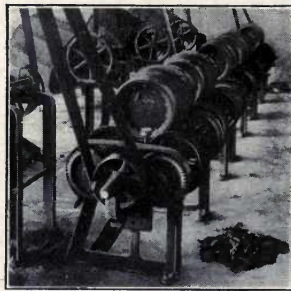
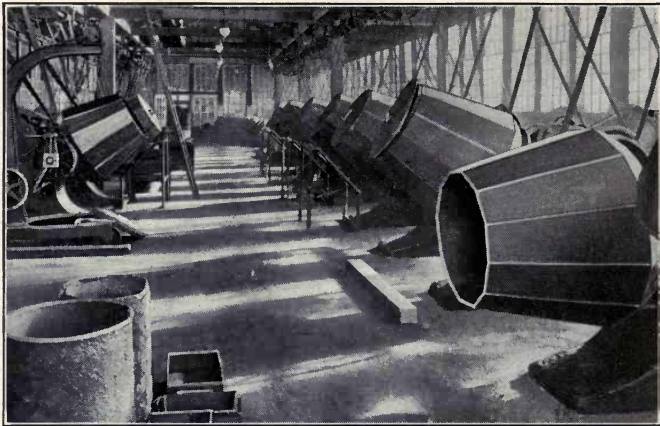
Micro-Chrome



MICRO-CHROME OIL GRINDING DEPARTMENT—The Micro-Chrome Ball is our specialty. It is the last word in ball manufacture and is the product of great care exercised in the special Micro-Chrome Oil Grinding Department. Careful selection of abrasives and care in their use is essential to produce the oil ground finish, which, when polished, will be perfectly smooth, mirror-like and accurate.



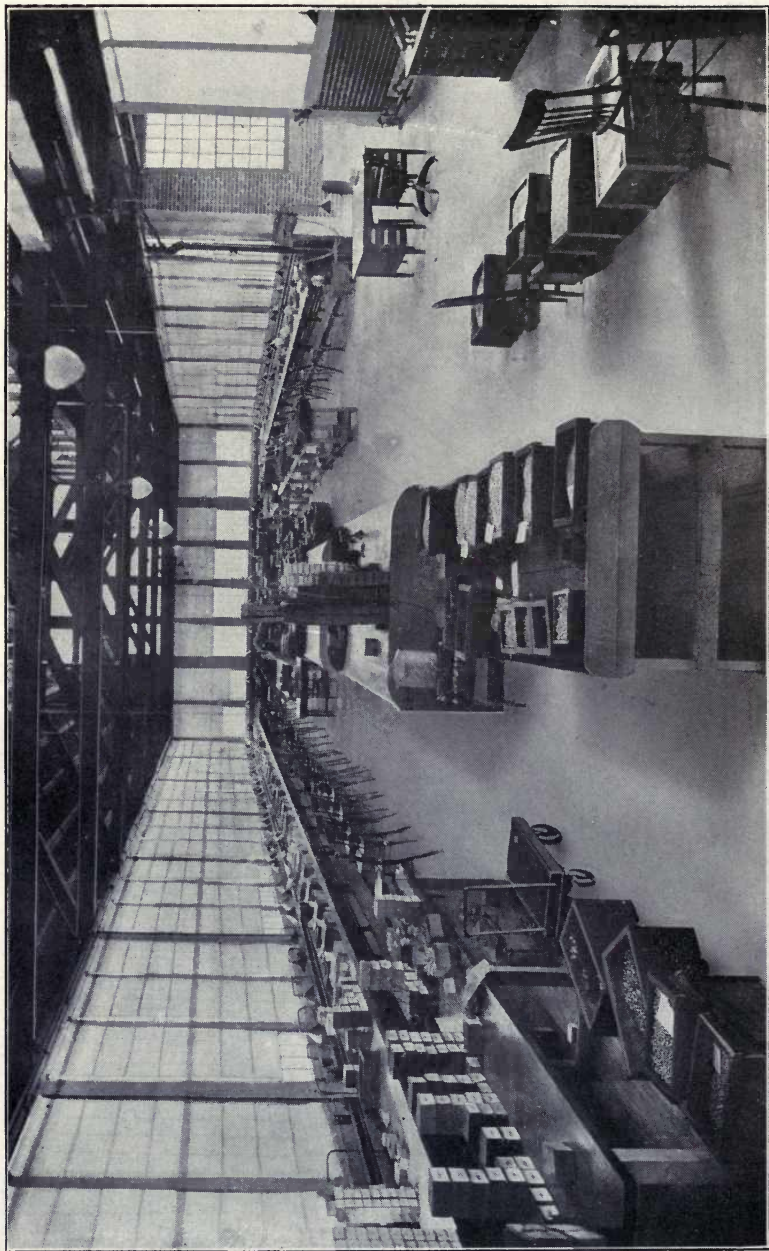
COMMERCIAL OIL-GRINDING DEPARTMENT—Our commercial grade of ball is made on special ring grinding machines, which produce a smoothness and accuracy entirely sufficient for general ball bearing work.



THE TUMBLING BARREL ROOM—This room is equipped with a variety of tumbling barrels, cleaning barrels and rotary kegs, all of which serve some special purpose, depending upon the size of ball or the grade of finish desired.



ONE CORNER OF THE BALL STORAGE ROOM—Here millions of balls in various stages of finish are stored awaiting completion. Blanks and balls are inspected carefully after every operation, and are rejected or accepted just as rigidly as they are in the final Inspection Departments.

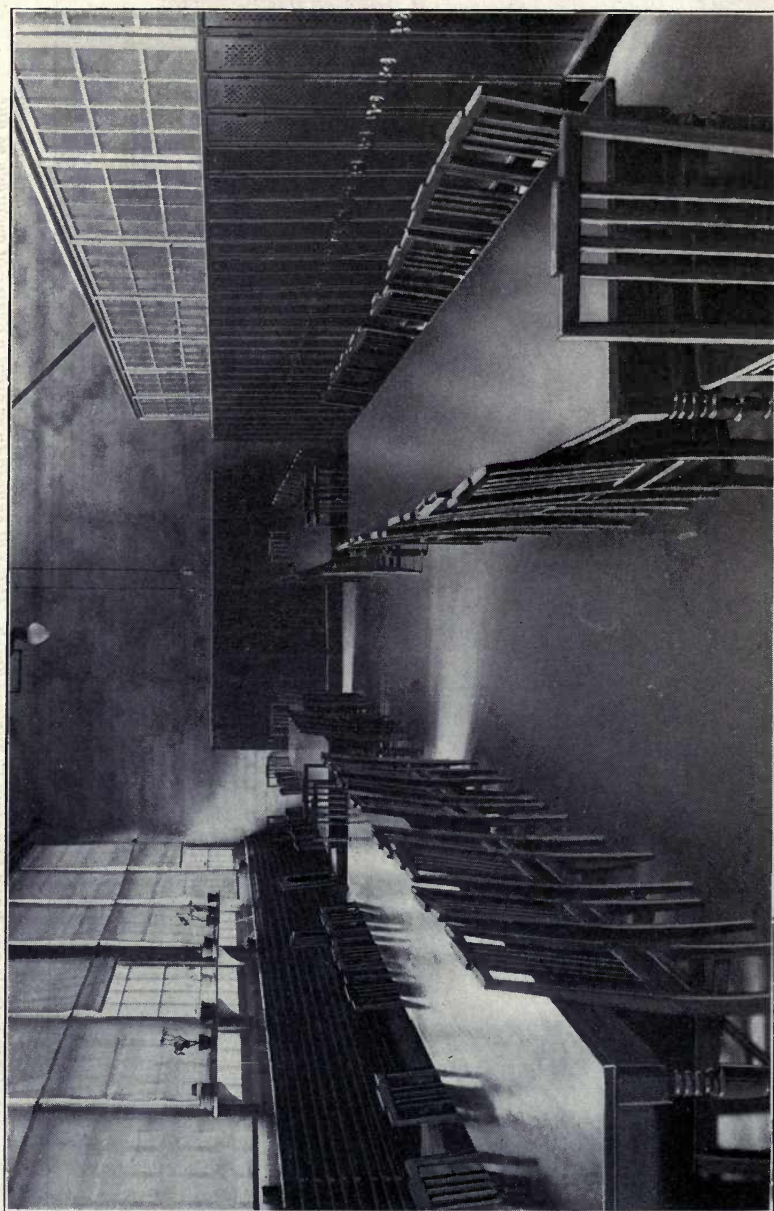


MICRO-CHROME INSPECTION AND GAUGING DEPARTMENT—Our very highest grade of ball (the Micro-Chrome) is inspected and gauged in a separate room from the commercial grade. Every ball is inspected by at least two persons and every ball is gauged, the smaller sizes being automatically gauged while the larger sizes are gauged by hand. Millions of balls are thus inspected every day.

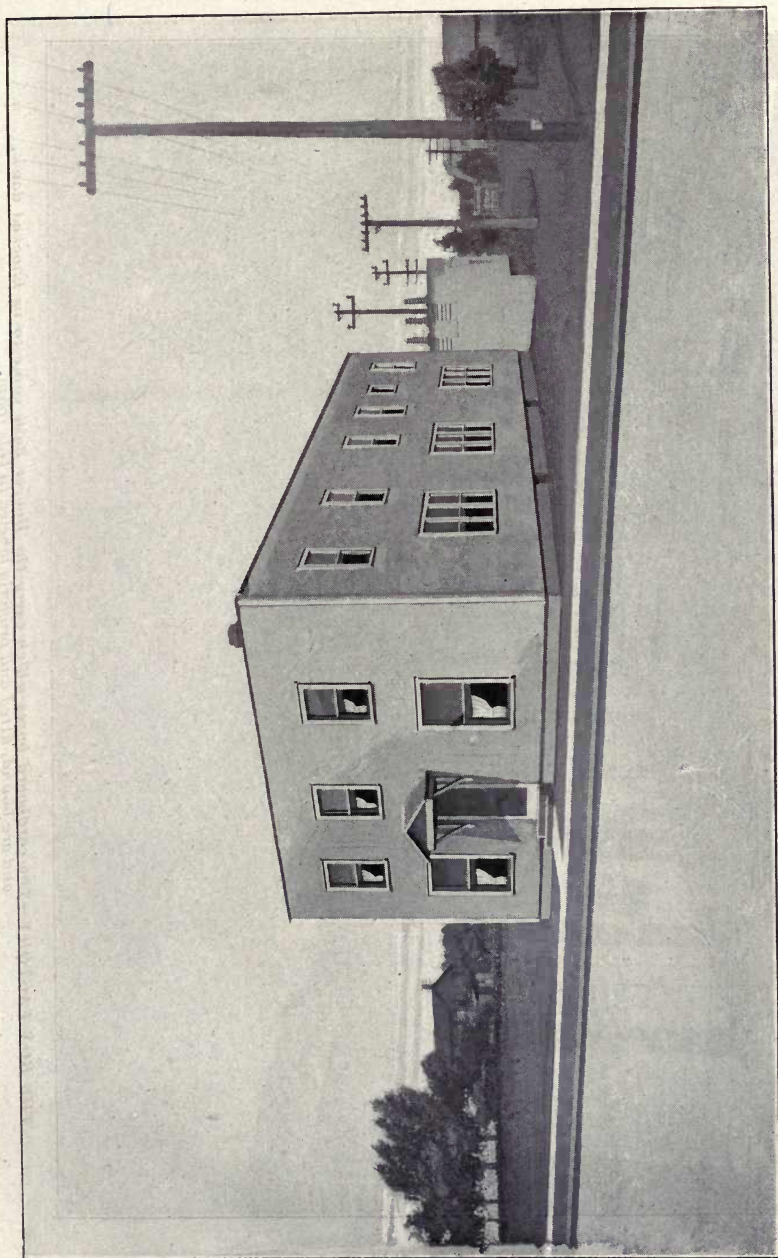
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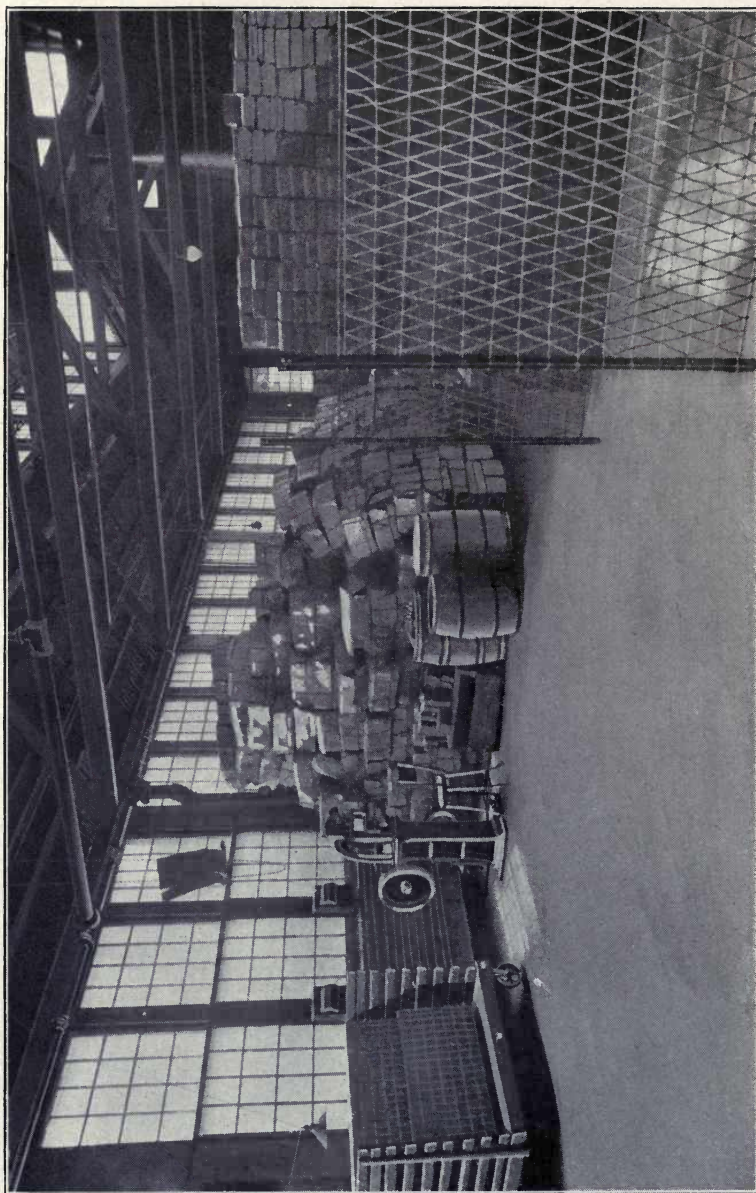
COMMERCIAL INSPECTION AND GAUGING DEPARTMENT—The commercial grade of ball is entirely free from defects and has a fine smooth surface finish. It is not gauged to as great a degree of accuracy as our Micro-Chrome grade. It has a great field of usefulness, however, for general ball bearing work.



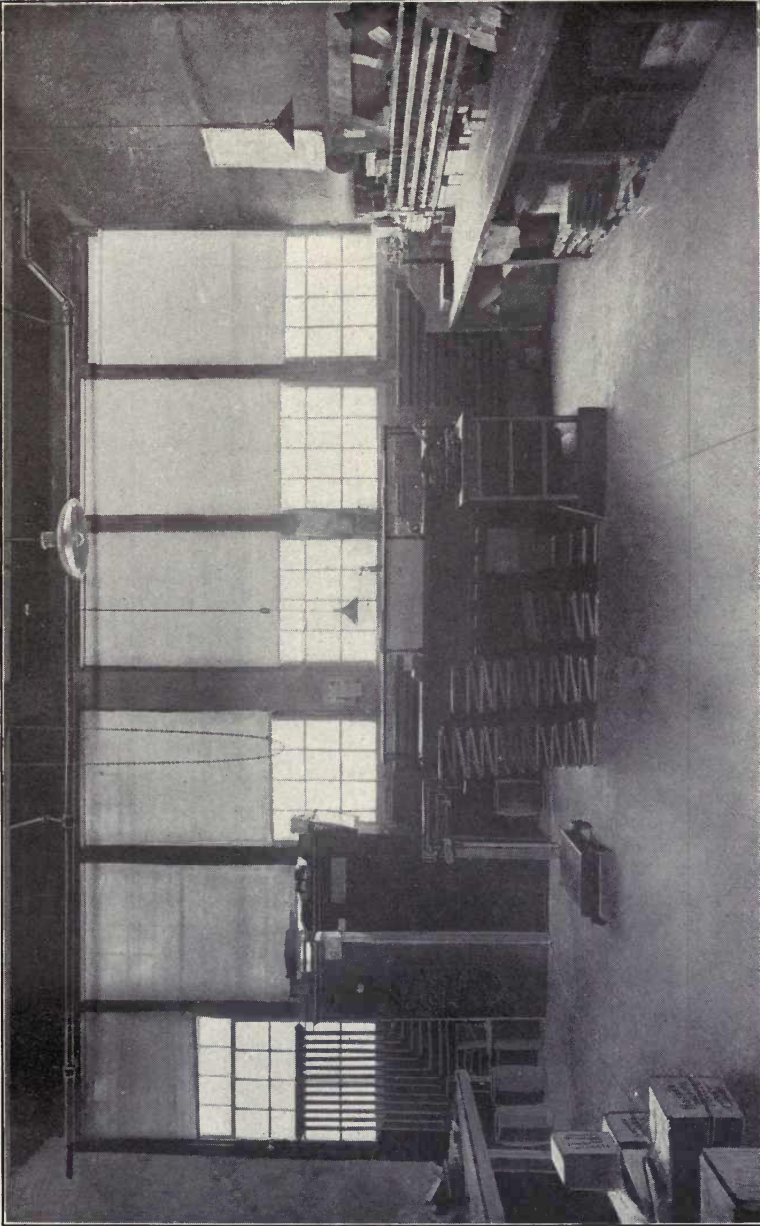
GIRLS' LUNCH AND LOCKER ROOM—Adjoining the Inspection Department in which girls are employed.



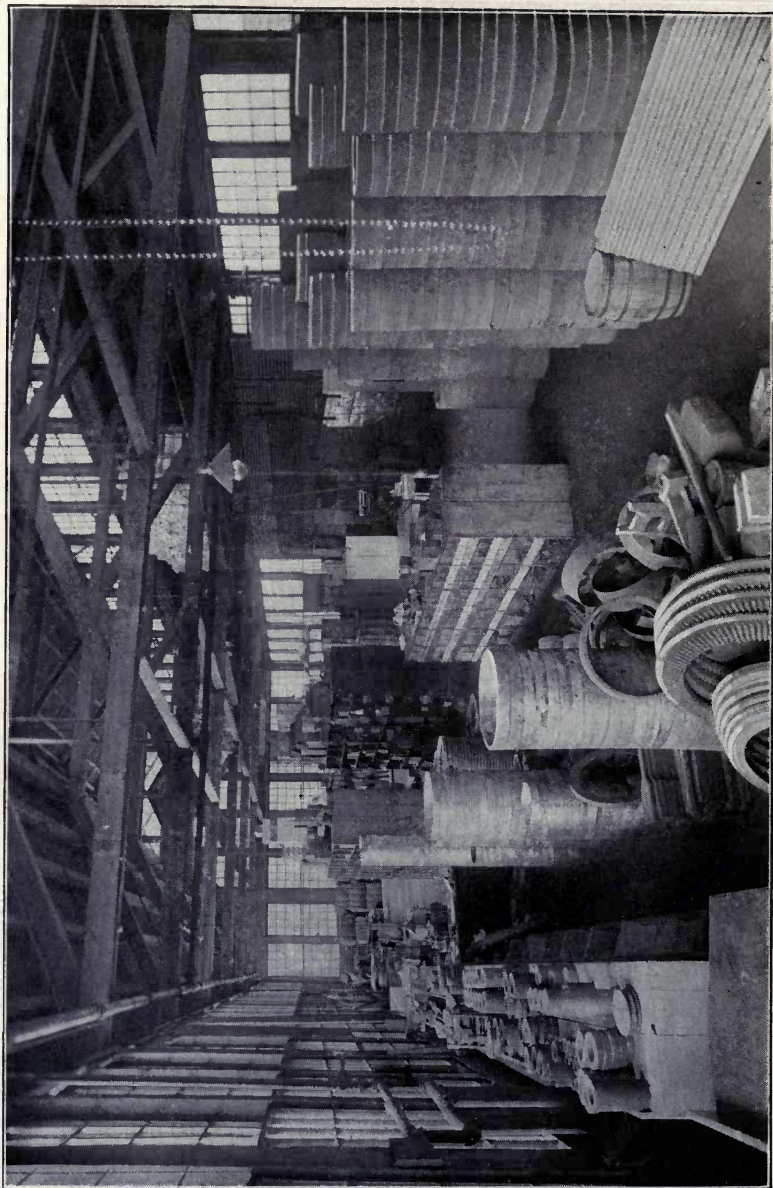
EMPLOYEE'S RESTAURANT—A restaurant is maintained by the Company on the premises for the use of the employees. It is open both day and night.



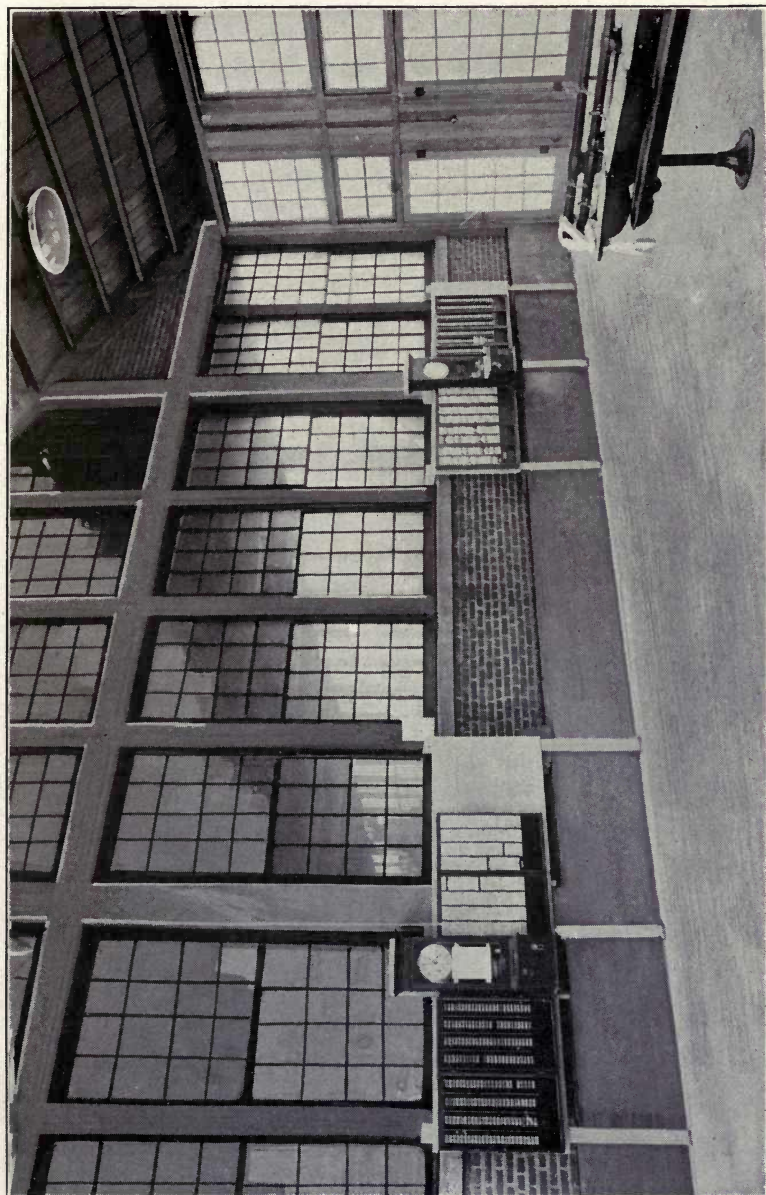
THE BOX FACTORY—The cardboard boxes which carry the Hoover Rolls come to us knocked down, and are bound, fitted and properly labeled in this room.



SHIPPING DEPARTMENT—From 8 to 10 tons of finished balls go through this department every working day. We pride ourselves in the neatness and strength of the boxes which carry our balls to all parts of this country and the world.



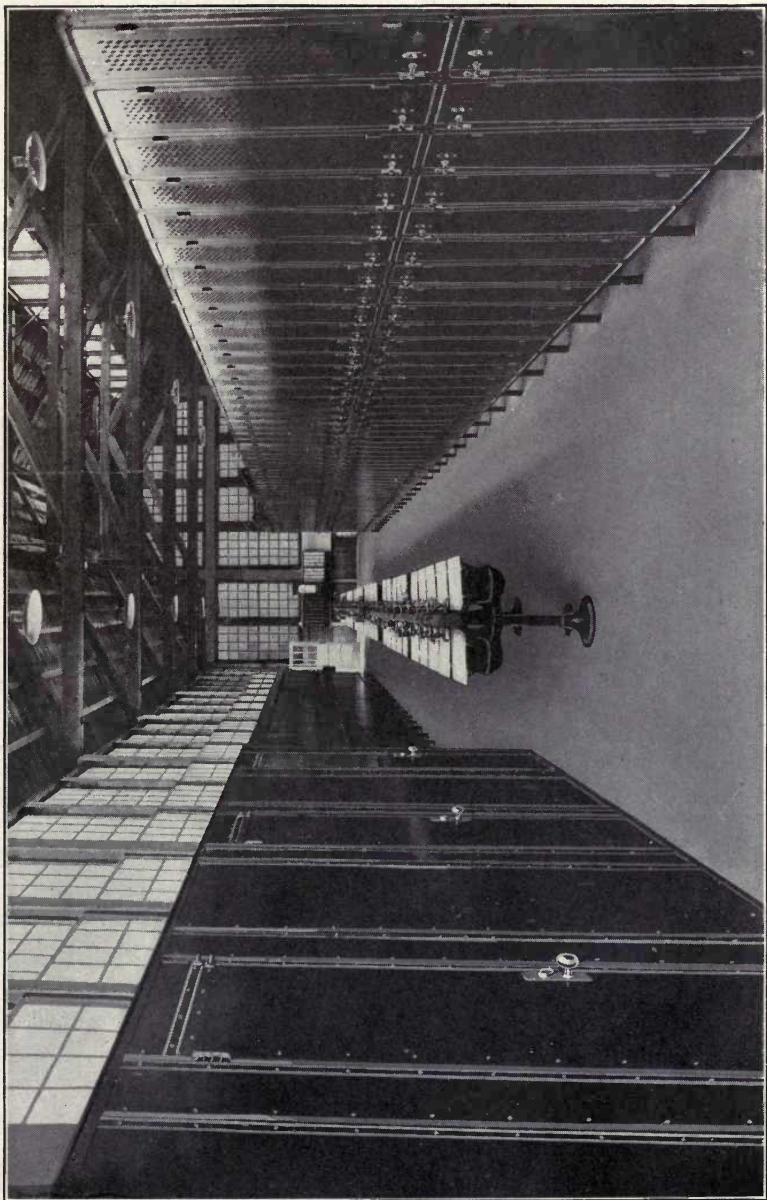
THE STOCK ROOM—where materials and supplies used throughout the plant are stored until requisitioned by the various departments.



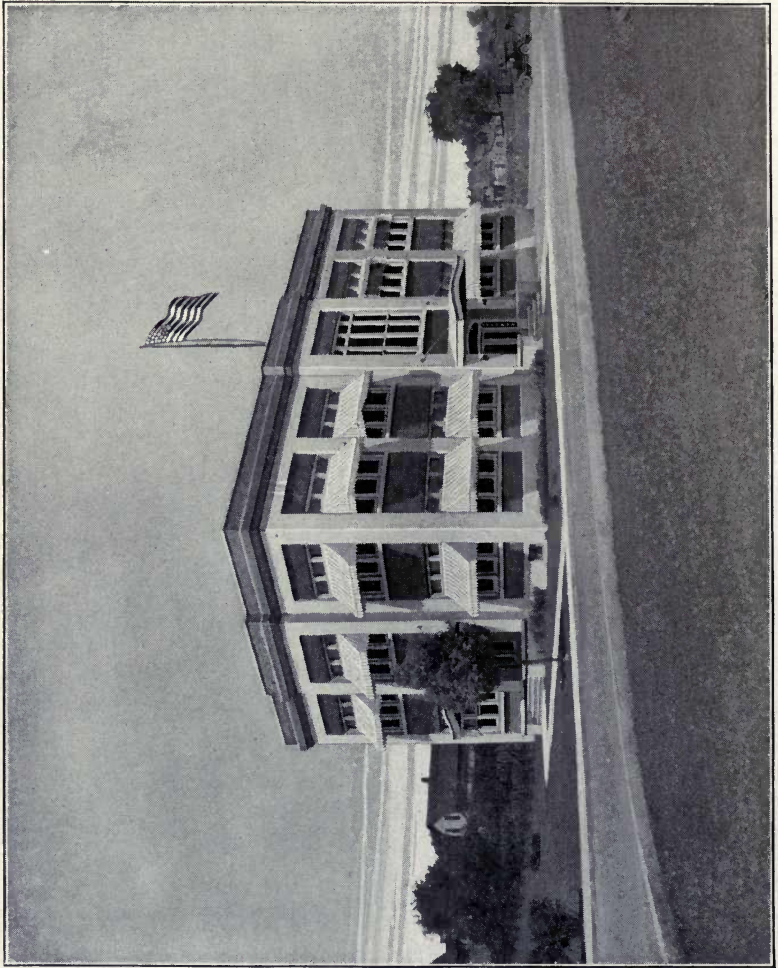
SIX TIME CLOCKS—are necessary to accommodate the employees who pass through this room when entering or leaving the plant.



THE LOCKER AND WASH ROOMS—Ample locker room and washing facilities are provided every workman in the Hoover factory.



Another view of locker and wash rooms.

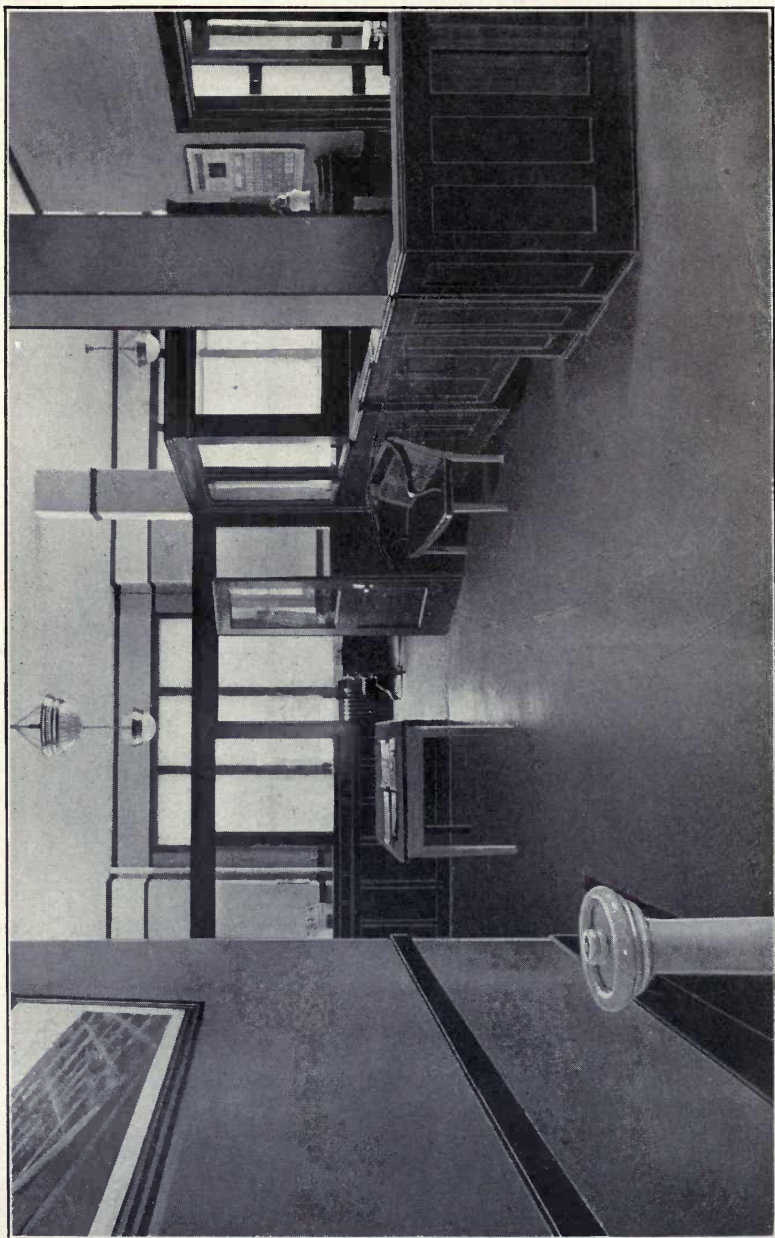


General Offices

THE
OFFICE OF THE
PRESIDENT AND
GENERAL MANAGER



Office of President and General Manager.



Corridor on Main Floor of General Office Building.

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Portion of Main Office.

WEIGHTS OF STEEL BALLS

Diameter of Ball (Inches)	Decimal (Inches)	WEIGHT PER BALL		
		Grammes (Metric)	Ounces (Avoir)	Pounds (Avoir)
1-16	.0625	.0166	.00096	.00006
3-32	.09375	.0547	.00193	.00012
1-8	.125	.1302	.00457	.00029
5-32	.15625	.2552	.00898	.00056
3-16	.1875	.4408	.01552	.00097
7-32	.21875	.6993	.02461	.00154
1-4	.25	1.0463	.03680	.00230
9-32	.28125	1.4865	.05231	.00327
5-16	.3125	2.0415	.07184	.00449
11-32	.34375	2.7141	.09550	.00597
3-8	.375	3.5226	.12400	.00775
7-16	.4375	5.5871	.19722	.01229
1-2	.50	8.3498	.29392	.01837
9-16	.5625	11.8923	.41856	.02616
5-8	.625	16.2947	.57520	.03585
11-16	.6875	21.6873	.76336	.04771
3-4	.75	28.1872	.99200	.06200
13-16	.8125	35.7585	1.25872	.07867
7-8	.875	44.7872	1.57648	.09853
15-16	.9375	55.0169	1.93664	.12104
1	1.	66.8257	2.35232	.14702
1-1/16	1.0625	80.1379	2.8199	.17626
1-1/8	1.125	95.1271	3.3473	.20923
1-3/16	1.1875	111.8509	3.9369	.24608
1-1/4	1.25	130.4965	4.5919	.28702
1-5/16	1.3125	151.0656	5.3157	.33226
1-3/8	1.375	173.6764	6.1113	.38199
1-7/16	1.4375	198.4563	6.9833	.43649
1-1/2	1.50	225.4820	7.9343	.49594
1-9/16	1.5625	254.8682	8.9653	.56057
1-5/8	1.625	286.6917	10.0881	.63056
1-11/16	1.6875	321.0544	11.2973	.70614
1-3/4	1.75	358.0711	12.5998	.78756
1-13/16	1.8125	397.8185	13.9985	.87498
1-7/8	1.875	440.398	15.4968	.96864
1-15/16	1.9375	485.939	17.0993	1.06880
2	2.	534.491	18.8077	1.17559
2-1/8	2.125	641.101	22.5591	1.41007
2-1/4	2.25	761.019	26.7788	1.67382
2-3/8	2.375	895.037	31.4947	1.96859
2-1/2	2.50	1043.924	36.7340	2.29608
2-5/8	2.625	1208.474	42.5239	2.65798
2-3/4	2.75	1389.436	48.8916	3.05600
2-7/8	2.875	1587.727	55.8691	3.49213
3	3.	1803.881	63.4751	3.96755
3-1/8	3.125	2038.920	71.7457	4.48451
3-1/4	3.25	2293.482	80.7033	5.04440
3-3/8	3.375	2568.460	90.3792	5.64920
3-1/2	3.50	2864.492	100.7960	6.30031
3-5/8	3.625	3183.875	112.0345	6.99997
3-3/4	3.75	3523.164	123.9734	7.74903
3-7/8	3.875	3887.462	136.7923	8.55028
4	4.	4275.876	150.4599	9.40458
4-1/4	4.25	5128.882	180.4756	11.28073
4-1/2	4.50	6088.179	214.2314	13.39065
4-3/4	4.75	7160.402	251.9608	15.74896
5	5.	8351.420	293.4605	18.36854

C=Contents in Cubic Inches.

$$= \frac{4}{3} \pi R^3 = 4.1888 R^3 = .5236 D^3$$

W=Weight of Steel Balls in pounds.

$$= R^3 (.28065 \times 4.1888) = 1.17558 R^3 = .14695 D^3$$

FORMULA FOR DETERMINING PITCH DIA. OF BALL CIRCLE AND CLEARANCE BETWEEN BALLS

Notation:

D_1 = Pitch Dia. of Ball Circle.

D_2 = Dia. of Circumscribed Circle.

D_3 = Dia. of Inscribed Circle.

d = Dia. of Balls.

N = Number of Balls in the Ring.

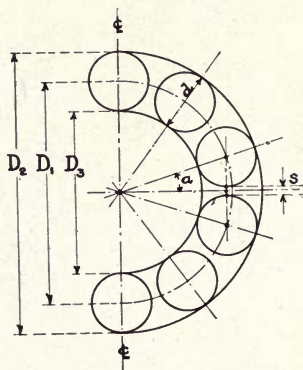
S = Clearance Between Each Pair of Balls.

$$D_1 = (d + S) \times \text{CSC.} \left(\frac{180^\circ}{N} \right)$$

$$D_2 = D_1 + d$$

$$D_3 = D_1 - d$$

$$S = D_1 \times \text{SIN.} \left(\frac{180^\circ}{N} \right) - d$$



The following table gives the value of the CSC. and SIN. for "N" Balls.

No. of Balls "N"	Angle a $\frac{180^\circ}{N}$	CSC. $\frac{180^\circ}{N}$	SIN. $\frac{180^\circ}{N}$
6	30°	2.00000	.50000
7	25°—42'—51.43"	2.30476	.43388
8	22°—30'	2.61313	.38268
9	20°	2.92381	.34202
10	18°	3.23607	.30902
11	16°—21'—49.09"	3.54947	.28173
12	15°	3.86370	.25882
13	13°—50'—46.16"	4.17858	.23932
14	12°—51'—25.72"	4.49396	.22252
15	12°	4.80973	.20791
16	11°—15'	5.12583	.19509
17	10°—35'—17.65"	5.44219	.18375
18	10°	5.75877	.17365
19	9°—28'—25.26"	6.07554	.16459
20	9°	6.39247	.15643
21	8°—34'—17.14"	6.70950	.14904
22	8°—10'—54.55"	7.02667	.14231
23	7°—49'—33.91"	7.34394	.13617
24	7°—30'	7.66130	.13053
25	7°—12'	7.97873	.12533
26	6°—55'—23.08"	8.29623	.12054
27	6°—40'	8.61380	.11609
28	6°—25'—42.86"	8.93140	.11196
29	6°—12'—24.82"	9.24907	.10812
30	6°	9.56677	.10453

THE CIRCLE

d = Diameter of Circle.
C = Circumference of Circle.

A = Area of Plane Surface.
 $\pi = 3.141593$

$$C = \pi d = 3.141593 d$$

$$A = \frac{\pi d^2}{4} = .785398 d^2$$

Areas of Circles are to Each other as the Squares of their Diameters.

THE SPHERE

d = Diameter of Sphere.
S = Area of Convex Surface.

V = Volume of Sphere.

$$S = \pi d^2 = 3.141593 d^2$$

$$V = \frac{\pi d^3}{6} = .523599 d^3$$

Surfaces of Spheres are to each other as the Squares of their Diameters.
The Volume of a Shpere = $\frac{2}{3}$ the Volume of its Circumscribing Cylinder.
Volumes of Spheres are to each other as the Cubes of their Diameters.

BALL DIA. IN INCHES	CIRCUM. N INCHES	AREA		VOLUME CU. INCHES
		SECTION SQ. INCHES	CONVEX SURFACE SQ. INCHES	
1/32	.09818	.00077	.00307	.00002
1/16	.19635	.00307	.01227	.00013
3/32	.29452	.00690	.02781	.00043
1/8	.39270	.01227	.04909	.00102
5/32	.49087	.01917	.07770	.00200
3/16	.58905	.02781	.11045	.00345
7/32	.68722	.03738	.15035	.00548
1/4	.78540	.04909	.19635	.00818
9/32	.88357	.06213	.24931	.01165
5/16	.98175	.07670	.30980	.01598
11/32	1.0799	.09281	.37745	.02127
3/8	1.1781	.11045	.44719	.02761
13/32	1.2763	.12962	.51849	.03511
7/16	1.3744	.15035	.60132	.04383
15/32	1.4726	.17257	.69695	.05385
1/2	1.5708	.19635	.79540	.06545
9/16	1.7671	.24260	.99403	.08319
5/8	1.9635	.30080	1.2272	.10785
11/16	2.1598	.37122	1.4949	.13704
3/4	2.3562	.44719	1.7971	.17208
13/16	2.5525	.51849	2.0730	.21304
7/8	2.7489	.60132	2.4035	.26077
15/16	2.9452	.69695	2.7911	.31545
1.	3.1416	.7854	3.1416	.35890
1/16	3.3379	.8806	3.5466	.42804
1/8	3.5343	.9940	3.9761	.50551
3/16	3.7306	1.1075	4.4301	.59181
1/4	3.9270	1.2272	4.9008	.68707
5/16	4.1233	1.3550	5.4119	.79189
3/8	4.3197	1.4849	5.9396	.90611
7/16	4.5160	1.6230	6.4919	1.0303
1/2	4.7124	1.7671	7.0686	1.1651
9/16	4.9087	1.9175	7.6699	1.3107
5/8	5.1051	2.0739	8.2957	1.4680
11/16	5.3014	2.2365	8.9461	1.6361
3/4	5.4978	2.4053	9.6211	1.8150
13/16	5.6941	2.5802	10.321	2.0050
7/8	5.8905	2.7612	11.044	2.2064
15/16	6.0868	2.9483	11.793	2.4193
2.	6.2832	3.1416	12.566	2.6439
1/16	6.4795	3.3410	13.364	2.8800
1/8	6.6759	3.5460	14.188	3.1283
3/16	6.8722	3.7583	15.035	3.3890
1/4	7.0686	3.9701	15.904	3.6621
5/16	7.2649	4.2000	16.800	3.9475
3/8	7.4613	4.4301	17.721	4.2454
7/16	7.6576	4.6604	18.668	4.5559
1/2	7.8540	4.9087	19.635	4.8793
9/16	8.0503	5.1574	20.620	5.2157
5/8	8.2467	5.4119	21.624	5.5650
11/16	8.4430	5.6727	22.649	5.9274
3/4	8.6394	5.9396	23.694	6.3029
13/16	8.8357	6.2122	24.759	6.6914
7/8	9.0321	6.4918	25.844	7.0929
15/16	9.2284	6.7771	26.949	7.5074
3.	9.4248	7.0686	28.274	8.0359
1/16	9.6211	7.3662	29.425	8.4774
1/8	9.8175	7.6699	30.600	8.9329
3/16	10.014	7.9798	31.810	9.4024
1/4	10.210	8.2955	33.045	9.8859
5/16	10.407	8.6179	34.304	10.3824
3/8	10.603	8.9462	35.584	10.8919
7/16	10.799	9.2806	36.884	11.4144
1/2	10.996	9.6211	38.204	11.9499
9/16	11.192	9.9678	39.544	12.4984
5/8	11.388	10.321	40.904	13.0599
11/16	11.585	10.680	42.284	13.6344
3/4	11.781	11.045	43.684	14.2219
13/16	11.977	11.416	45.104	14.8224
7/8	12.174	11.793	46.544	15.4359
15/16	12.370	12.177	48.004	16.0624
4.	12.566	12.566	50.000	16.7024

DECIMAL EQUIVALENTS OF FRACTIONS OF AN INCH

Fract.	Dec.	Fract.	Dec.	Fract.	Dec.	Fract.	Dec.
$\frac{1}{64}$	.015625	$\frac{17}{64}$	.265625	$\frac{33}{64}$	.515625	$\frac{49}{64}$	.765625
$\frac{1}{32}$	.03125	$\frac{9}{32}$	.28125	$\frac{17}{32}$	.53125	$\frac{25}{32}$	.78125
$\frac{3}{64}$	.046875	$\frac{19}{64}$	.296875	$\frac{35}{64}$	.546875	$\frac{51}{64}$	.796875
$\frac{1}{16}$	.0625	$\frac{5}{16}$	.3125	$\frac{9}{16}$	.5625	$\frac{13}{16}$	.8125
$\frac{5}{64}$	.078125	$\frac{21}{64}$	.328125	$\frac{37}{64}$	.578125	$\frac{53}{64}$	.828125
$\frac{3}{32}$	.09375	$\frac{11}{32}$	.34375	$\frac{19}{32}$	.59375	$\frac{27}{32}$	.84375
$\frac{7}{64}$	.109375	$\frac{23}{64}$	.359375	$\frac{39}{64}$	.609375	$\frac{55}{64}$	.859375
$\frac{1}{8}$	.125	$\frac{3}{8}$	.375	$\frac{5}{8}$	.625	$\frac{7}{8}$	.875
$\frac{9}{64}$	.140625	$\frac{25}{64}$	.390625	$\frac{41}{64}$	.640625	$\frac{57}{64}$	.890625
$\frac{5}{32}$	.15625	$\frac{13}{32}$	.40625	$\frac{21}{32}$	.65625	$\frac{29}{32}$	.90625
$\frac{11}{64}$	.171875	$\frac{27}{64}$	.421875	$\frac{43}{64}$	.671875	$\frac{59}{64}$	.921875
$\frac{3}{16}$	.1875	$\frac{7}{16}$	.4375	$\frac{11}{16}$	.6875	$\frac{15}{16}$	.9375
$\frac{13}{64}$	.203125	$\frac{29}{64}$	.453125	$\frac{45}{64}$	.703125	$\frac{61}{64}$	.953125
$\frac{7}{32}$	.21875	$\frac{15}{32}$	.46875	$\frac{23}{32}$	.71875	$\frac{31}{32}$	.96875
$\frac{15}{64}$	.234375	$\frac{31}{64}$	.484375	$\frac{47}{64}$	.734375	$\frac{63}{64}$	.984375
$\frac{1}{4}$	.25	$\frac{1}{2}$	.5	$\frac{3}{4}$	.75	1	

TABLE OF DECIMAL EQUIVALENTS OF MILLI- METERS AND FRACTIONS OF MILLIMETERS

$\frac{1}{100}$ mm. = .0003937".

mm. Inches	mm. Inches	mm. Inches	mm. Inches	mm. Inches
$\frac{1}{50}$ = .00079	$\frac{11}{50}$ = .00866	$\frac{21}{50}$ = .01654	$\frac{31}{50}$ = .02441	$\frac{41}{50}$ = .03228
$\frac{2}{50}$ = .00157	$\frac{12}{50}$ = .00945	$\frac{22}{50}$ = .01732	$\frac{32}{50}$ = .02520	$\frac{42}{50}$ = .03307
$\frac{3}{50}$ = .00236	$\frac{13}{50}$ = .01024	$\frac{23}{50}$ = .01811	$\frac{33}{50}$ = .02598	$\frac{43}{50}$ = .03386
$\frac{4}{50}$ = .00315	$\frac{14}{50}$ = .01102	$\frac{24}{50}$ = .01890	$\frac{34}{50}$ = .02677	$\frac{44}{50}$ = .03465
$\frac{5}{50}$ = .00394	$\frac{15}{50}$ = .01181	$\frac{25}{50}$ = .01969	$\frac{35}{50}$ = .02756	$\frac{45}{50}$ = .03543
$\frac{6}{50}$ = .00472	$\frac{16}{50}$ = .01260	$\frac{26}{50}$ = .02047	$\frac{36}{50}$ = .02835	$\frac{46}{50}$ = .03622
$\frac{7}{50}$ = .00551	$\frac{17}{50}$ = .01339	$\frac{27}{50}$ = .02126	$\frac{37}{50}$ = .02913	$\frac{47}{50}$ = .03701
$\frac{8}{50}$ = .00630	$\frac{18}{50}$ = .01417	$\frac{28}{50}$ = .02205	$\frac{38}{50}$ = .02992	$\frac{48}{50}$ = .03780
$\frac{9}{50}$ = .00709	$\frac{19}{50}$ = .01496	$\frac{29}{50}$ = .02283	$\frac{39}{50}$ = .03071	$\frac{49}{50}$ = .03858
$\frac{10}{50}$ = .00787	$\frac{20}{50}$ = .01575	$\frac{30}{50}$ = .02362	$\frac{40}{50}$ = .03150	

10 mm. = 1 Centimeter = 0.3937 inches
 10 cm. = 1 Decimeter = 3.937 inches
 10 dm. = 1 Meter = 39.37 inches
 25.4 mm. = 1 English Inch.

CONVERSION TABLE

DECIMAL EQUIVALENTS OF MILLIMETERS IN INCHES

1 m/m to 500 m/m.

1 m/m = .03937027"

m.m.	Inches	m.m.	Inches	m.m.	Inches	m.m.	Inches	m.m.	Inches	m.m.	Inches	m.m.	Inches
1	.03937027	73	2.87402971	145	5.70868915	216	8.50397892	287	11.29926749	358	14.09455666	429	16.88954588
2	.07874054	74	2.91339998	146	5.74805942	217	8.54334859	288	11.33863776	359	14.13392693	430	16.92916101
3	.11811081	75	2.95277025	147	5.78742969	218	8.58271886	289	11.37800803	360	14.17329720	431	16.96877609
4	.15748108	76	2.99214052	148	5.82679996	219	8.62208913	290	11.41737830	361	14.21266744	432	17.00750664
5	.19685135	77	3.03151079	149	5.86617023	220	8.66145940	291	11.45674857	362	14.25203774	433	17.04732691
6	.23622162	78	3.07088106	150	5.90554050	221	8.70082967	292	11.49611884	363	14.29140801	434	17.08699718
7	.27559189	79	3.11025133	151	5.94491077	222	8.74019994	293	11.53549811	364	14.33077828	435	17.12667455
8	.31496216	80	3.14962106	152	5.98428104	223	8.77957021	294	11.57483938	365	14.37014853	436	17.16643772
9	.35433243	81	3.18899187	153	6.02365131	224	8.81894048	295	11.61422963	366	14.40951882	437	17.20608799
10	.39370270	82	3.22836214	154	6.06302158	225	8.85831073	296	11.65399992	367	14.44888909	438	17.24471826
11	.43307297	83	3.26773241	155	6.10239185	226	8.89768102	297	11.69370198	368	14.48825936	439	17.28334853
12	.47244324	84	3.30710268	156	6.14176212	227	8.93705129	298	11.73234046	369	14.52762963	440	17.32291880
13	.51181351	85	3.34647295	157	6.18113239	228	8.97642156	299	11.77107073	370	14.56699990	441	17.36228907
14	.55118378	86	3.38584322	158	6.22050266	229	9.01579183	300	11.81001001	371	14.60637017	442	17.40165934
15	.59055405	87	3.42521349	159	6.25987293	230	9.05516210	301	11.85043127	372	14.64574044	443	17.44102961
16	.62992432	88	3.46458376	160	6.29924320	231	9.09453237	302	11.88982154	373	14.68510701	444	17.48039988
17	.66929459	89	3.50395403	161	6.33861347	232	9.13390264	303	11.92919181	374	14.72448098	445	17.51977015
18	.70866486	90	3.54332430	162	6.37798374	233	9.17327291	304	11.96856208	375	14.76385125	446	17.55914042
19	.74803513	91	3.58269457	163	6.41735401	234	9.21264318	305	12.00793235	376	14.80322152	447	17.59851069
20	.78740540	92	3.62206484	164	6.45672428	235	9.25201345	306	12.04730262	377	14.84259179	448	17.63788096
21	.82677567	93	3.66143511	165	6.49609455	236	9.29138372	307	12.08667289	378	14.88196206	449	17.67725123
22	.86614594	94	3.70080538	166	6.53546482	237	9.33075399	308	12.12604316	379	14.92133233	450	17.71662150
23	.90551621	95	3.74017565	167	6.57483509	238	9.37012426	309	12.16541343	380	14.96070260	451	17.75599177
24	.94488648	96	3.77954592	168	6.61420536	239	9.40949453	310	12.20478370	381	15.00007287	452	17.79536204
25	.98425675	97	3.81891619	169	6.65357563	240	9.44886480	311	12.24415397	382	15.03944314	453	17.83473231
26	1.02362702	98	3.85828646	170	6.69294590	241	9.48823507	312	12.28352424	383	15.07881341	454	17.87410258
27	1.06299729	99	3.89765673	171	6.73231617	242	9.52760534	313	12.32289451	384	15.11818368	455	17.91347285
28	1.10236756	100	3.93702700	172	6.77168644	243	9.56697561	314	12.36226478	385	15.15755398	456	17.95284312
29	1.14173783	101	3.97639727	173	6.81105671	244	9.60634588	315	12.40163505	386	15.19692425	457	17.99221339
30	1.18110810	102	4.01576754	174	6.85042698	245	9.64571615	316	12.44100532	387	15.23629449	458	18.03158366
31	1.22047837	103	4.05513781	175	6.88979723	246	9.68508642	317	12.48037559	388	15.27566476	459	18.07095393
32	1.25984864	104	4.09450808	176	6.92916752	247	9.72445669	318	12.51974586	389	15.31503503	460	18.11032420
33	1.29921891	105	4.13387835	177	6.96853779	248	9.76382696	319	12.55911613	390	15.35440530	461	18.14969447
34	1.33858918	106	4.17324862	178	7.00790806	249	9.80319723	320	12.59848640	391	15.39377557	462	18.18906474
35	1.37795945	107	4.21261889	179	7.04727833	250	9.84256750	321	12.63785667	392	15.43314584	463	18.22843501
36	1.41732972	108	4.25208916	180	7.08664860	251	9.88193777	322	12.67722694	393	15.47251611	464	18.26780528
37	1.45669999	109	4.29135943	181	7.12601887	252	9.92130804	323	12.71659721	394	15.51188638	465	18.30717555
38	1.49607026	110	4.33072970	182	7.16538914	253	9.96067831	324	12.75596748	395	15.55125665	466	18.34654582
39	1.53544053	111	4.37009997	183	7.20475941	254	10.00004858	325	12.79533775	396	15.59062692	467	18.38591609
40	1.57481080	112	4.40947024	184	7.24412968	255	10.03941885	326	12.83470802	397	15.62999719	468	18.42528636
41	1.61418107	113	4.44884051	185	7.28350095	256	10.07878912	327	12.87407829	398	15.66936746	469	18.46465663
42	1.65355134	114	4.48821078	186	7.32287122	257	10.11815939	328	12.91344856	399	15.70873773	470	18.50402690
43	1.69292161	115	4.52758105	187	7.36224149	258	10.15752966	329	12.95281883	400	15.74810800	471	18.54339717
44	1.73229188	116	4.56695132	188	7.40161176	259	10.19689993	330	12.99218910	401	15.78747827	472	18.58276744
45	1.77166215	117	4.60632159	189	7.44098103	260	10.23627020	331	13.03155937	402	15.82684854	473	18.62213771
46	1.81103242	118	4.64569186	190	7.48035130	261	10.27564047	332	13.07092964	403	15.86621881	474	18.66150798
47	1.85040269	119	4.68506213	191	7.51972157	262	10.31501074	333	13.11029991	404	15.90558908	475	18.70087825
48	1.88977296	120	4.72443240	192	7.55899284	263	10.35438101	334	13.14967018	405	15.94495935	476	18.74024852
49	1.92914323	121	4.76380267	193	7.59846311	264	10.39375128	335	13.18904045	406	15.98432962	477	18.77961879
50	1.96851350	122	4.80317294	194	7.63783238	265	10.43312155	336	13.22841072	407	16.02369989	478	18.81898906
51	2.00788377	123	4.84254321	195	7.67720265	266	10.47249182	337	13.26778099	408	16.06307016	479	18.85835933
52	2.04725404	124	4.88191348	196	7.71657292	267	10.51186208	338	13.30715126	409	16.10244043	480	18.89772960
53	2.08662431	125	4.92128375	197	7.75594319	268	10.55123236	339	13.34652153	410	16.14181070	481	18.93709987
54	2.12599458	126	4.96065402	198	7.79531346	269	10.59060263	340	13.38589180	411	16.18118097	482	18.97647014
55	2.16536485	127	5.00002429	199	7.83468373	270	10.62997290	341	13.42526207	412	16.22055124	483	19.01584041
56	2.20473512	128	5.03939456	200	7.87405400	271	10.66934317	342	13.46463234	413	16.25992151	484	19.05521068
57	2.24410539	129	5.07876483	201	7.91342427	272	10.70871344	343	13.50400261	414	16.29929178	485	19.09458095
58	2.28347566	130	5.11813510	202	7.95279454	273	10.74808371	344	13.54337288	415	16.33866205	486	19.13395122
59	2.32284593	131	5.15750537	203	7.99216481	274	10.78745398	345	13.58274315	416	16.37803232	487	19.17332149
60	2.36221620	132	5.19687564	204	8.03153508	275	10.82682425	346	13.62211342	417	16.41740259	488	19.21269176
61	2.40158647	133	5.23624591	205	8.07090535	276	10.86619452	347	13.66148369	418	16.45677286	489	19.25206203
62	2.44095674	134	5.27561618	206	8.11027562	277	10.90556479	348	13.70085396	419	16.49614313	490	19.29143230
63	2.48032701	135	5.31498645	207	8.14964589	278	10.94493506	349	13.74022423	420	16.53551340	491	19.33080257
64	2.51969728	136	5.35435672	208	8.18901616	279	10.98430533	350	13.77959450	421	16.57488367	492	19.37017284
65	2.55906755	137	5.39372699	209	8.22838643	280	11.02367560	351	13.81896477	422	16.61425394	493	19.40954311
66	2.59843782	138	5.43309726	210	8.26775670	281	11.06304587	352	13.85833504	423	16.65362421	494	19.44891338
67	2.63780809	139	5.47246753	211	8.30712697	282	11.10241614	353	13.89770531	424	16.69299448	495	19.48828365
68	2.67717836	140	5.51183780	212	8.34649724	283	11.14178641	354	13.93707558	425	16.73236475	496	19.52765392
69	2.71654863	141	5.55120807	213	8.38586751	284	11.18115668	355	13.97644585	426	16.77173502	497	19.56702419
70	2.75591890	142	5.59057834	214	8.42523778	285	11.22052695	356	14.01581612	427	16.81110529	498	19.60639446
71	2.79528917	143	5.62994861	215	8.46460805	286	11.25989722	357	14.05518639	428	16.85047556	499	19.64576473
72	2.83465944	144	5.66931888								500	19.68513500	

CONVERSION TABLE

MILLIMETER EQUIVALENTS OF FRACTIONAL INCHES

1/4 inch to 12⁶³/₆₄ Inches

	1"	2"	3"	4"	5"	6"	7"	8"	9"	10"	11"	12"
1/64	0.3906	25.3905	50.7900	76.1986	101.598	126.998	152.397	177.797	203.196	228.596	253.995	279.394
1/32	0.7812	25.7864	51.1539	76.5554	101.955	127.354	152.754	178.153	203.553	228.952	254.352	279.751
3/64	1.1718	26.1922	51.5928	76.9923	102.391	127.791	153.190	178.590	203.990	229.389	254.789	280.188
1/16	1.5625	26.5901	51.9896	77.3892	102.788	128.188	153.588	178.987	204.386	229.786	255.186	280.585
5/64	1.5874	26.9870	52.3865	77.7860	103.185	128.585	153.984	179.384	204.783	230.183	255.582	280.982
5/64	1.9843	27.3838	52.7834	78.1829	103.582	128.982	154.381	179.781	205.180	230.580	255.979	281.379
3/32	2.3812	27.7807	53.1802	78.5798	103.979	129.378	154.780	179.205	205.577	230.977	256.376	281.776
7/64	2.7780	28.1776	53.5771	78.9766	104.376	129.775	155.175	180.574	205.974	231.373	256.773	282.173
1/8	3.1749	28.5744	53.9740	79.3735	104.773	130.172	155.572	180.971	206.370	231.770	257.170	282.569
9/64	3.5718	28.9713	54.3708	79.7704	105.169	130.569	155.969	181.368	206.768	232.167	257.567	282.966
5/32	3.9686	29.3682	54.7677	80.1672	105.566	130.966	156.365	181.765	207.164	232.564	257.964	283.363
11/64	4.3655	29.7650	55.1646	80.5641	105.963	131.363	156.762	182.162	207.561	232.961	258.360	283.760
3/16	4.7624	30.1619	55.5614	80.9610	106.360	131.760	157.159	182.559	207.958	233.358	258.757	284.157
13/64	5.1592	30.5588	55.9583	81.3579	106.757	132.156	157.556	182.956	208.355	233.755	259.154	284.554
7/32	5.5561	30.9556	56.3552	81.7547	107.154	132.553	157.953	183.352	208.752	234.152	259.551	284.951
15/64	5.9530	31.3525	56.7520	82.1516	107.551	132.950	158.350	183.749	209.149	234.549	259.948	285.347
1/4	6.3498	31.7493	57.1489	82.5485	107.948	133.347	158.747	184.146	209.546	234.945	260.345	285.744
17/64	6.7467	32.1462	57.5458	82.9453	108.344	133.744	159.143	184.543	209.943	235.342	260.742	286.141
9/32	7.1436	32.5431	57.9426	83.3422	108.741	134.141	159.540	184.940	210.339	235.739	261.139	286.538
19/64	7.5404	32.9400	58.3395	83.7391	109.138	134.538	159.937	185.337	210.736	236.136	261.536	286.935
5/16	7.9373	33.3368	58.7364	84.1359	109.535	134.935	160.334	185.734	211.133	236.532	261.932	287.332
21/64	8.3342	33.7337	59.1333	84.5328	109.932	135.331	160.731	186.131	211.530	236.929	262.329	287.729
11/32	8.7310	34.1306	59.5301	84.9297	110.329	135.728	161.128	186.527	211.927	237.326	262.726	288.126
23/64	9.1279	34.5274	59.9270	85.3265	110.726	136.125	161.525	186.924	212.324	237.723	263.123	288.523
3/8	9.5248	34.9243	60.3239	85.7234	111.122	136.522	161.922	187.321	212.721	238.120	263.520	288.920
25/64	9.9216	35.3212	60.7207	86.1203	111.519	136.919	162.318	187.718	213.118	238.517	263.917	289.317
13/24	10.3185	35.7180	61.1176	86.5171	111.916	137.316	162.715	188.115	213.515	238.914	264.314	289.714
27/64	10.7154	36.1149	61.5145	86.9140	112.313	137.713	163.112	188.512	213.912	239.311	264.711	290.111
7/16	11.1122	36.5118	61.9113	87.3109	112.710	138.109	163.509	188.909	214.308	239.708	265.107	290.507
29/64	11.5091	36.9087	62.3082	87.7077	113.107	138.506	163.906	189.305	214.705	240.105	265.504	290.903
15/32	11.9060	37.3055	62.7051	88.1046	113.504	138.903	164.303	189.702	215.102	240.501	265.901	291.300
31/64	12.3029	37.7024	63.1019	88.5015	113.901	139.300	164.700	190.099	215.499	240.898	266.298	291.697
1/2	12.6997	38.0993	63.4988	88.8983	114.297	139.697	165.097	190.496	215.896	241.295	266.695	292.094
33/64	13.0966	38.4951	63.8957	89.2952	114.694	140.094	165.493	190.893	216.292	241.692	267.092	292.491
17/32	13.4934	38.8930	64.2925	89.6921	115.091	140.491	165.890	191.290	216.689	242.089	267.489	292.888
35/64	13.8903	39.2899	64.6894	90.0890	115.488	140.888	166.287	191.687	217.086	242.486	267.885	293.285
9/16	14.2872	39.6867	65.0863	90.4858	115.885	141.284	166.684	192.084	217.483	242.883	268.282	293.681
37/64	14.6841	40.0836	65.4831	90.8827	116.282	141.681	167.081	192.480	217.880	243.279	268.679	294.079
19/32	15.0810	40.4805	65.8800	91.2795	116.679	142.078	167.478	192.877	218.277	243.676	269.076	294.476
39/64	15.4778	40.8773	66.2769	91.6764	117.075	142.475	167.875	193.274	218.674	244.073	269.473	294.873
5/8	15.8747	41.2742	66.6737	92.0733	117.472	142.872	168.271	193.671	219.071	244.470	269.870	295.269
41/64	16.2715	41.6711	67.0706	92.4701	117.869	143.269	168.668	194.068	219.467	244.867	270.266	295.666
21/32	16.6684	42.0679	67.4675	92.8670	118.266	143.666	169.065	194.465	219.864	245.263	270.663	296.063
43/64	17.0652	42.4648	67.8643	93.2639	118.663	144.063	169.462	194.862	220.261	245.660	271.060	296.460
11/16	17.4621	42.8617	68.2612	93.6608	119.060	144.459	169.859	195.258	220.658	246.057	271.457	296.857
45/64	17.8590	43.2585	68.6581	94.0576	119.457	144.856	170.256	195.655	221.055	246.454	271.854	297.253
23/16	18.2559	43.6554	69.0549	94.4545	119.854	145.253	170.653	196.052	221.452	246.851	272.251	297.650
47/64	18.6527	44.0523	69.4518	94.8513	120.250	145.650	171.050	196.449	221.849	247.248	272.648	298.047
3/4	19.0496	44.4491	69.8487	95.2482	120.647	146.047	171.446	196.846	222.245	247.645	273.045	298.444
49/64	19.4465	44.8460	70.2455	95.6451	121.044	146.444	171.843	197.242	222.642	248.042	273.441	298.841
25/32	19.8433	45.2429	70.6424	96.0419	121.441	146.841	172.240	197.640	223.039	248.439	273.838	299.238
51/64	20.2402	45.6397	71.0393	96.4388	121.838	147.237	172.637	198.037	223.436	248.836	274.235	299.635
13/16	20.6371	46.0366	71.4362	96.8357	122.235	147.634	173.034	198.433	223.833	249.232	274.632	300.032
53/64	21.0340	46.4335	71.8330	97.2326	122.632	148.031	173.431	198.830	224.230	249.629	275.029	300.429
27/32	21.4308	46.8303	72.2299	97.6294	123.029	148.428	173.828	199.227	224.627	250.026	275.426	300.826
55/64	21.8277	47.2272	72.6267	98.0263	123.425	148.825	174.224	199.624	225.024	250.423	275.823	301.223
7/8	22.2245	47.6241	73.0236	98.4232	123.822	149.222	174.621	200.021	225.421	250.820	276.220	301.620
57/64	22.6214	48.0209	73.4205	98.8200	124.219	149.619	175.018	200.418	225.817	251.217	276.616	302.016
29/16	23.0183	48.4178	73.8173	99.2169	124.616	150.016	175.415	200.815	226.214	251.614	277.013	302.413
59/64	23.4151	48.8147	74.2142	99.6137	125.013	150.413	175.812	201.211	226.611	252.011	277.410	302.810
15/8	23.8120	49.2116	74.6111	100.0101	125.410	150.809	176.209	201.608	227.008	252.407	277.807	303.207
61/64	24.2089	49.6084	75.0080	100.4069	125.807	151.206	176.606	202.005	227.405	252.804	278.204	303.603
31/32	24.6057	50.0053	75.4048	100.8034	126.203	151.603	177.003	202.402	227.802	253.201	278.601	304.000
63/64	25.0025	50.4021	75.8017	101.2001	126.600	152.000	177.399	202.799	228.198	253.598	279.004	304.397

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